Innovation in hip protector design: Challenging function, meaning and context

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Thesis submitted in partial fulfilment of the requirements for the Degree of Doctor of Philosophy (PhD)

University of the Arts London / Falmouth University

April 2024

Acknowledgements

There are many people I would like to thank for their support throughout the process of researching and writing this thesis. I am very grateful to my supervision team, Dr Simon Clarke (Director of Studies), Professor Colin Roberts, and Drummond Masterton, for their help shaping the research project, their continual guidance and encouragement. Martin Matthews, Managing Director at DM Orthotics, has been a great supporter of the project, and the advice and prototyping expertise provided by Anna Short has been invaluable.

Insights into the contexts of ageing, falls and protective clothing have very kindly been provided by Pat O'Brien at Cornwall Care and the team at Mountford House care home. Fashion designer, Fanny Karst, also generously shared her experience and insights into designing clothing for older women. Thanks also to Tony Ka Yui Wang at Bodywear Lab for his helpful advice on sportswear design. Helen Tite and Pat Taylor at iCareiMove have been tremendous advocates for the project. They introduced me to their wonderful exercise class participants, to whom I am so hugely grateful for giving their time and enthusiasm to our discussions. Thank you to the Royal Osteoporosis Society for their help promoting my online survey, and particular thanks to their members who took the time to complete it.

I am very grateful to the support provided by the technicians at Falmouth University. I would especially like to thank Peter Doubleday for his help, and patience, in the hot works garment construction workshop. A huge thanks also to Oliver Hatfield for support with 3D printing, and John Peters for advice on all CAD matters. My students on the BA(Hons) Sustainable Product Design course have engaged in many discussions relating to the themes in the PhD and I'm grateful for their interest and probing questions. In particular, I would like to thank the student group who helped during final evaluation stages of the design processes.

Finally, I would like to thank my family for their continuous love and support throughout the years as the PhD has progressed. Special thanks to Rachael Jones who has been an absolute rock and spurred me on through the more challenging times.

This PhD thesis is dedicated to the memory of my amazing sister, Sara Smith, who sadly died in December 2021. Sara was a devoted mum and dedicated NHS nurse who thrived on helping others. Her compassion and support for people in need remains a constant source of inspiration.

Abstract

Older people are at higher risk of falls than the rest of the population and more susceptible to hip fractures. The consequences of this injury in old age can be severe, leading to long-term disability and a reduction in healthy life years. Hip protectors, consisting of underwear with integrated pads over the hip joint, can reduce the risk of fracture. However, long term adoption of these products is low due to aesthetics, discomfort, difficulty of use, and acceptance of fall risk.

This practiced-based PhD embraces human-centred design methodologies, using insights from potential hip protector users, to support prototyping of new types of garments. The research challenges the existing medical model for the design of hip protectors, typically perceived as 'assistive technology', and questions how human-centred design practice can identify overlooked criteria that resonates with social and cultural sensitivities. Younger people with mobility difficulties, or conditions such as osteoporosis, are also at risk of falls so the notion of products for the 'elderly' is also challenged.

Innovations in materials and manufacturing processes, including 3D printing and inflatable shape changing surfaces are investigated through the practice. These technologies are evaluated in relation to essential performance requirements and how visual and tactile properties can reflect a new design language for hip protectors.

The research draws from fashion theory and clothing semiotics, investigating the identity and meanings associated with hip protectors. The understanding of the social and cultural bearings of these garments, and the notion of fashion as communication, is integral to this research in developing new approaches that satisfy both physiological and psychological user needs.

Knowledge claims exist at the junction between technological innovation, critical gerontology, and clothing semiotics, proposing new approaches to garment design to reduce the risk of hip fractures. The practice responds to a conceptual framework reflecting these domains to develop human-centred 'Hipwear' design solutions.

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1 Introduction

In this practice-based PhD design research project, I examine the context of hip fractures in people at risk of accidental falls and fragility fractures. Wearing hip protector garments, typically underwear shorts with integrated protective pads positioned over the hip joints, is an established approach to reduce the risk of hip fracture. However, several barriers exist that impact on the acceptance and long-term adoption of these types of products, reducing their efficacy in clinical trials. The research seeks to understand these barriers, embracing people centred and inclusive design methods. In doing so, I have explored new approaches to hip protection that are more sensitive to the needs of a diverse range of users.

Technological innovation occurs through the investigation of materials and processes to improve the design and performance of hip protector garments. From a social perspective, innovation in hip protector design is embraced by challenging the meanings interpreted through current products. The design of hip protectors can problematise ageing through stigmatised garments that do not follow cultural norms of clothing. This research project attempts to shift their associations from dependency to empowerment with hip protector designs aligned to lifestyle aspirations rather than physical decline. A critical gerontological approach attempts to broaden the contexts of hip protector use to tackle ageism, or the way someone might be 'othered' due to their risk of falls or fragility fractures.

Research outputs that have emerged directly from the PhD research project and thesis writing include:

- Design for Health journal, Vol 7, Issue 1, Mar 2023: Human-centred design research during the pandemic: Using an online survey to inform personas of women at risk of hip fracture. (Andrews 2023)(See Appendix A).
- [Design – Creative Practice – Research][3] Symposium, Design Museum, London, Nov 2022: Human-centred design research during the pandemic: Using an online survey to inform personas of women at risk of hip fracture.
- Innovation Breakfast Club, Royal Cornwall Hospitals NHS Trust, Jun 2022: Innovation in hip protector design: challenging function, meaning and context (overview of PhD research project).
- Falmouth PGR Spring Symposium, Falmouth University, Mar 2020: Garments of empowerment or dependency? Shifting the visual language of hip protection.

- The Design Journal, Vol 22, Issue sup 1, May 2019: Designing better hip protectors: a critical and contextual review examining their acceptance and adoption in older populations. (Andrews 2019)(See Appendix B).
- European Academy of Design conference: Running with Scissors, University of Dundee, April 2019: Designing better hip protectors: a critical and contextual review examining their acceptance and adoption in older populations.
- Falmouth PGR Summer Symposium, Falmouth University, Jun 2018: Hip protectors: garment or equipment?

The PhD project is supported by the 3D3 Centre for Doctoral Training and funded by the Arts and Humanities Research Council (AHRC). The PhD studentship is fully funded through the National Productivity Investment Fund (NPIF).

1.1 The context, scope and rationale for the research

Hip fractures are a major cause of long-term disability and can lead to a rapid decrease in healthy life years, especially for older people. They are the most common reason for older people to need emergency anaesthesia and surgery and the most common cause of death following an accident (Royal College of Physicians 2018). In 2016, over 65,000 people aged 60 or over suffered a hip fracture in the UK (Royal College of Physicians 2017), and the average age of a person who fractures their hip is 77 years (National Institute for Health and Care Excellence 2023). The annual cost of medical and social care for all the hip fracture cases in the UK amounts to about £2 billion (National Institute for Health and Care Excellence 2023). In the US, where there are approximately 150,000 hip fractures per year, the estimated cost of care is between $10.3 billion and $15.2 billion (Gillespie 2001; Burge et al. 2007). In 1999, the total annual number of hip fractures worldwide was predicted to rise from 1.6 million to 6.2 million by 2050 if no action was taken to reduce the growing health crisis (Kannus et al. 1999). However, there are now already over 10 million cases per year globally (Wu et al. 2021; Sing et al. 2023) demonstrating a rapid rise during the last two decades.

The effectiveness of reducing hip fracture risk when wearing hip protectors is well reported in early studies, especially relating to long term care contexts. For example, Hubacher and Wettstein (2001) report that 50% of all hip fractures can be prevented if hip protectors are worn. They assert that the reason the number of preventable hip fractures is not higher, “is not due to any shortcomings in the

mechanical protective effect of hip protectors but to insufficient willingness to wear them on the part of fall-prone senior citizens". More recently, a study by Korall et al. (2019) showed a three-fold reduction in hip fractures among care home residents if they were wearing a hip protector at the time of the fall. However, study participants find hip protectors uncomfortable or dislike the way they look, which can negatively impact on the clinical effectiveness of intervention studies using hip protectors due to lack of compliance and limited 'wearing time' (Kurrle et al. 2004). Researchers have even investigated ways of more accurately measuring compliance using sensors built into the hip protectors (Wong et al. 2022). This issue is reflected in the latest Cochrane Review on hip protectors for preventing hip fractures in older people. The authors found evidence for a small reduction in hip fracture risk in nursing or residential care settings, but little or no effect in hip fracture risk from trials in the community. They also conclude that poor acceptance of hip protectors by older people is a barrier to their use, noting that, "better understanding is needed of the personal and design factors that may influence acceptance and adherence." (Santesso et al. 2014). This is a critical part of the research presented in this thesis, grounded in the initial contextual review of literature and design practice (see chapter 2 Contextual Review).

Human-centred design research methods, directly engaging with industry experts and potential hip protector users (see chapter 4 Hipwear: Discover and define phases), have informed the design practice, and shifted the focus beyond the technology-centred design approaches of current hip protector designs. A social model for design has been embraced, challenging the conventions of medical models that dominate the design of hip protectors. In this respect, the principles of inclusive design are practiced throughout this research project. The Design Council describes inclusive design as a general approach to designing whereby products and services address the needs of the widest possible audience, irrespective of age or ability (Clarkson and Coleman 2015). The barriers to use of current hip protector garments demonstrate how many users are excluded by their design. Critical to an inclusive design approach, project partner, iCareiMove, have been key to gaining access to potential user insights. DM Orthotics have also provided industry expertise and knowledge relating to performance garments. The relationship with these organisations is expanded further (see 3.5) alongside the broader methodological approach to the research (see chapter 3 Methodology).

Through practice-based design research, innovation in new types of hip protectors has emerged (see chapter 5 Hipwear: Develop and deliver phases). Although much is written about the act and meaning of 'innovation' (e.g. Robert Randall 2005; Marchand 2022; Hallonsten 2023), this is not an area of investigation for this research project. The use of the term 'innovation' in the thesis title, and where referred to in the text, follows the standard Oxford English Dictionary definition: "The action of innovating; the introduction of novelties; the alteration of what is established by the introduction

of new elements or forms" (Oxford English Dictionary 2024). Erlhoff and Marshall's definition can also be applied, describing innovation in design as a, "change in the development, production, distribution, or use of an artifact, environment, or system that is perceived as being different from its precedents by its proposed users or target audience" (2008: 219). The ambition for this PhD investigation is that the innovation in hip protector design is not only perceived as being *different* from its precedents, but also much improved.

Improvement related to the environmental performance of clothing and textiles more broadly is a key tenet of the EU's Ecodesign for Sustainable Products Regulation (ESPR) which entered into force in July 2024 (European Commission 2024). The ESPR will contribute to the transition to a circular, sustainable and competitive economy by extending the scope of the earlier Ecodesign Directive (that applied only to energy-related products) to almost all physical products, including garments (Boniolo 2022; European Commission 2024). The regulation enforces ecodesign requirements relating to durability, reusability, repairability, fibre-to-fibre recyclability and mandatory recycled fibre content. For example, requirements could link to colour fastness, tear strength, quality of zippers and seams, or measures to curb the release of microplastics (Boniolo 2022). The ESPR will introduce Digital Product Passports (DPP) as a digital identity card for products that holds relevant information to support the products' sustainability. The information will be available electronically to make it easier for consumers and manufacturers to make informed decisions about sustainability, and authorities to check regulatory compliance. The requirements of the ESPR underpins design thinking and material specification of hip protector garments to ensure they meet sustainability criteria as we transition to a circular economy (see 2.3.2, 2.3.4, 5.4.3.2 and 5.4.3.3).

The underperforming design of current hip protectors, reflected through user exclusion and lack of acceptance, represents another clear opportunity for innovation. This research has sought to understand how hip protection can challenge existing precedents, to look, feel, and operate, in a way that is sensitive to the sociocultural and lifestyle aspirations of people most at risk of falls, including older people or adults of any age at higher risk of bone fractures. This includes over 3.5 million people living with osteoporosis in the UK, a disease that causes low bone mass and deterioration of bone tissue, who are at higher risk of fragility fractures (National Institute for Health and Care Excellence 2017). One in two women over 50 will break a bone because of the condition (Royal Osteoporosis Society 2022a).

Trial evidence on falls prevention interventions (although not including hip protectors) concludes that exercise is the most effective way of preventing falls in people aged 70 and over (Bruce et al. 2021). Indeed, both weight bearing exercises with impact (such as walking or star jumps) and muscle

strengthening exercises are recommended to people with osteoporosis as a way to keep bones strong and healthy (Royal Osteoporosis Society 2024). In response to this, the research has explored how hip protector garments can reflect the needs of 'active agers', promote movement through exercise, and healthy living into older age. The biggest challenge, and where the richest aspect of the research lies, is understanding that receptivity is key. How do we design garments that people at risk of falls would actually want to wear?

1.2 Research question and objectives

Hip protectors are an effective way of reducing the risk of hip fractures in older populations, but only when they are actually worn. Barriers to the acceptance of hip protectors are well reported within an ageing demographic resistant to the fact that they are becoming more vulnerable, and less independent (see 2.2.3). From a medical engineering perspective, most hip protectors fulfil the practical requirement of reducing the risk of hip fractures. From a design perspective, these products do not fulfil expectations in terms of comfort, aesthetics and ease-of-use (Sims-Gould et al. 2014). The understanding of the social and cultural bearings of hip protector garments, and the notion of fashion as communication, is critical in developing new approaches that satisfy both physiological and psychological needs. One key research question, therefore, dominates this PhD investigation:

How can hip protector garments be designed to fulfil performance requirements whilst embodying a visual language that sensitively reflects the sociocultural and lifestyle aspirations of the people who would benefit the most from wearing them?

There are five sub-questions that are derived directly from this overarching enquiry:

1. *…hip protector garments…* What precedents exist for the design of hip protector products and how can these be developed or challenged?
2. *…fulfil performance requirements…* Beyond reducing hip fracture risk, what are other performance requirements exist across the lifecycle of the product?
3. *…embodying a visual language…* What meanings do hip protectors communicate as garments?
4. *…sensitively reflects the sociocultural and lifestyle aspirations…* What are these aspirations and how can they be appropriately represented through material and aesthetic judgements?
5. *…the people who would benefit the most…* Which people are most at risk of hip fracture?

Questions three and four are interconnected and both apply to the meaning making aspects of hip protectors. Question three invites an investigation into the meanings of current hip protectors to understand where positive or negative associations are perceived. Question four focuses on the material and aesthetic choices for new hip protector garments that will emphasise the positive associations with the product.

The final question is particularly important for an investigation that embraces inclusive design principles. The language used represents an intentional shift away from research about 'old' people. Statistically, older populations are at greater risk of falls and should be considered a primary demographic for the development of new products that reduce the risk of hip fractures. However, many people, of all ages, experience mobility difficulties that might make a fall more likely. Similarly, for sufferers of osteoporosis the implication of a fall could have far worse consequences than for someone who does not have the condition.

In considering design solutions that might be accepted across different age groups, the research focus is not the design of products for 'old people', which is itself a significant barrier to acceptance because of the negative connotations associated with ageing that are culturally engrained. By expanding the context of hip protection requirements, the research will inform design solutions that could potentially be diversified into other markets, such as protective sportswear.

The following project objectives underpin this practice-based PhD investigation:

- Establish hip protector precedents and understand barriers to acceptance.
- Identify key areas for development through literature review and empirical research.
- Identify materials and technologies (e.g. energy absorbing polymers, 3D printed structures, inflatable surfaces) responding to user needs, evaluating potential applications and sustainability.
- Establish a conceptual framework of principles that underpin the inclusive design approach and sensitive visual language.
- Develop iterative design concepts, in response to human-centred design research, that test the conceptual framework, investigating performance requirements and visual language.
- Manufacture, test and evaluate prototypes with people to define design solutions.

1.3 Opportunities for new insights

The key areas where contributions to knowledge will be made are:

- Methodologies and artefacts relating to the technical development of novel impact absorbing surfaces that can be integrated into garments.
- A conceptual framework providing a lens through which the practice-based design research can be evaluated that could be generalised across the design of products for healthy ageing.
- Design criteria, currently overlooked in existing hip protector garments, informed by an inclusive design approach that establishes a new visual language for these products.

New insights will exist in the junction between technological innovation, critical gerontology, and clothing semiotics, proposing new approaches to garment design to reduce the risk of hip fractures. The practice will test theory in these domains to develop human-centred design solutions that challenge existing products that tend to be technology-centred in their approach.

Within the published literature, no peer reviewed articles concerning the design of hip protectors are found in any journals related to product or fashion design (except for work I have published from this PhD investigation). The lack of discourse on this topic within the design community presents a clear opportunity for new insights in this domain. Similarly, the market review suggests that existing hip protector products are generally sold through organisations that specialise in mobility aids and assistive technologies, mostly targeting concerned relatives or institutions purchasing in volume. This demonstrates an opportunity for new approaches to hip protectors, setting an agenda for better designed products aligned with lifestyle aspirations of people vulnerable to falls.

Many barriers exist that prevent the acceptance of hip protectors and long-term compliance. Hip protectors are garments, but the academic interrogation of these products as clothing is very limited. Discourse concerning the design of hip protectors largely focuses on engineering and technical factors. However, a broader philosophical enquiry, underpinning a human centred design approach, and dealing with issues relating to meaning and identity is clearly long overdue.

2 Contextual review

In the contextual review, I explore three key research areas. Section 2.1 presents the theoretical foundation through which knowledge is constructed for this practice-based design research investigation. It provides a grounding base for the later sections of the contextual review and underpins the conceptual framework – an understanding of how the research question will best be explored (Grant and Osanloo 2015) – discussed in section 2.4.

Section 2.2 investigates the context of accidental falls and hip fractures, precedents for hip protector design, and barriers to their acceptance. I draw on the paper I presented at the European Academy of Design (EAD) conference, in April 2019, titled, 'Designing better hip protectors: a critical and contextual review examining their acceptance and adoption in older populations'. The paper has subsequently been published in a special issue of The Design Journal (Andrews 2019), and is presented in Appendix B.

Finally, section 2.3 is a practice review examining the broader territory of protective clothing and garment technologies. This includes an investigation into energy absorbing materials that are, or could be, applied to the design of hip protectors. The domain of protective clothing relating to sportswear, digital manufacturing, and airbag technologies, is also explored.

Throughout the contextual review, I have investigated relevant literature and examples of practice, providing the contextual and theoretical basis for practice-based design research in response to the earlier research question. My approach reflects the transdisciplinary nature of this research project; as a product designer, I have engaged with the topics of critical gerontology, clothing semiotics, and inclusive design, whilst also exploring the fields of biomechanical engineering and fashion and textiles design.

2.1 Theoretical foundation for the study

In this section, I explore key theories that will later underpin the development of a conceptual framework. Grant and Osanloo (2015) liken conducting a PhD research project to building a house, where the construction blueprint is a metaphor for the theoretical framework. They note that without the theoretical foundation, "the structure and vision for a study is unclear, much like a house that cannot be constructed without a blueprint" (Grant and Osanloo 2015). Following this principle,

the ideas presented in the theoretical foundation underpin the understanding of how to plan the research, and the concepts and theories that are relevant to the topic. This is consolidated in section 2.4 where the conceptual framework is established.

The principle of critical gerontology is discussed whilst exploring how negative perceptions of ageing and ageist attitudes often stigmatise products designed for older people. The principles of clothing semiotics are used to investigate the way these ideas are embodied in a visual language commonly expressed in underwear hip protectors. I explore theory relating to the 'meaning making' aspect of design, including ways of negotiating the meanings associated with hip protectors. Finally, I examine how approaching the design of these garments as consumer products, as opposed to medical orthoses, opens a discourse that challenges the current function, meaning and context of hip protectors.

2.1.1 The culture of ageing

By 2050 the proportion of over 65s in the worldwide population will have doubled from 8.5% today to 16.7% (Coughlin 2017). A diverse demographic of older people is swelling as 'baby boomers' advance into their seventies. This is a generation for whom the notion of youth, independence, and demand for products that excite and delight, are culturally ingrained. In an article published in 1989 in American Demographics, Jeff Ostroff outlined seven key business opportunities created by an ageing population, noting, "Baby boomers won't age gracefully, creating an enormous marketing industry centred on health and fitness." (Ostroff 1989). Around the same time, the trend forecaster, Faith Popcorn, predicted a reinterpretation of the definition of aging, "a kind of de-aging of every tier of society" (Popcorn 1992: 57). She coined the term 'down-ageing' as a refusal to be bound by traditional age limitations, presenting baby boomers as an enormous market opportunity. However, although older people are viewed positively as a consumer group, the process of ageing still has negative connotations. A report by the Centre for Ageing Better (2020) highlights the ageist attitudes that exist in the UK, arguing that older people are mostly seen as incompetent, hostile or a burden.

Across many markets targeted at older people, the promise of products that meet their lifestyle aspirations and goals has not been met. Coughlin (2017) refers to Maslow's hierarchy of needs and how most products designed specifically for older adults only relate to the bottom level. He notes the widening gap between what older adults theoretically need, according to traditional narratives of ageing, and their actual demands as consumers. He rightly argues that designers addressing these

needs, “must reject the idea that older people are little more than a bundle of medical problems to be solved and instead prioritise their goals and aspirations” (Coughlin 2017: 281).

Within the research community too, traditional approaches to gerontology have problematized old people. "Historically, gerontological research conceived older people as research ‘subjects’ and framed aging itself as a ‘problem’ in a bio-medical model of inevitable ‘decline and loss’." (Barnes 2018: 66). Julia Twigg, whose research has focused on fashion and ageing, refers to age as a master identity that clearly demonstrates difference. However, sociology has tended to focus on other differentiators such as gender, class, race and sexuality. Age is taken for granted, seen anchored in physiology as opposed to the social spectrum (Twigg 2013). Only recently has the sociology of old age, or cultural gerontology, become established in academic research. Sawchuk (1995) describes a conference on ‘consumer attitudes, problems and needs of older consumers’, held in the mid-1970s. The literature accompanying the conference highlighted the disinterest in older people at the time, noting that only three doctoral dissertations in the field of gerontology were published since the 1930s, all of which were no longer available. The research landscape has shifted significantly since then with researchers such as Barnes and Taylor (2007) advocating critical gerontology as a, “value-committed approach to social gerontology – a commitment not just to understand the social construction of ageing but to change it” (Phillipson and Walker 1987).

In understanding the social context of old age and active engagement with hip protection, a critical gerontological approach seems highly appropriate. Katz (2015) notes that when older people are judged to be at risk of falls, their participation in falls prevention programs can be stigmatising, creating a fear of falling that can lead to a resistance to fall-preventing physical activities. Citing research by Nyman (2011), he continues, “It is not surprising that positive programs that stress maintaining independence, weight reduction, having fun, building strength with confidence, and, above all, not being judged by age, are the most successful” (Katz 2015: 168). In this scenario, changing the social construction of ageing can foster greater levels of engagement with fall prevention initiatives. Similarly, changing the narrative of wearing hip protectors from a signifier of decline to a practice of pro-active, healthy ageing, engages an approach centred within critical gerontology.

There is a growing field of research exploring how ageing and dress overlaps critical gerontology and fashion theory (e.g., Holland 2004; Twigg 2007, 2010, 2012, 2013, 2017, 2020; Hurd Clarke et al. 2009; Lee and Sontag 2010; Lee 2011; Lövgren 2016; Franklin 2017; Naranch 2020). Twigg (2013) conducted interviews with older women to examine how older age impacted on clothing choices. She found that age was not the sole or primary factor in their responses, and that much of what they

said was general to their lives and the kind of clothes they liked in the past and now. “They did not see themselves as greatly different from the person they had been earlier, and in their eyes still were.” (Twigg 2013: 54). However, changes to body shape accounted for the frustration for many of her interviewees who could not find clothes that fitted them well in later life. She also remarks, “it was clear that respondents used clothes to mask or compensate for bodily transgressions and to hide how their bodies fell short of the cultural ideal” (Twigg 2013: 59). This reflects the findings of Hurd Clarke et al. (2009) who conducted in-depth interviews with 36 women aged 71 to 93 years old. They found that many women’s clothing choices were constrained by changes to their bodies, “including weight gain, altered body shapes, wrinkles and sagging or ‘flabby’ arms and necks” (Hurd Clarke et al. 2009). Both Twigg (2013) and Hurd Clarke (2010) observe this internalised ageism in the highly negative ways older women have learnt to evaluate their bodies and appearance.

Old age as a specific part of the life course – and negativity associated with this stage – is a relatively recent social construct. Hareven (1995) demonstrates that the culture of old age before the 20th century places older people in a less distinct category of adulthood. Segmentation of the life course into more formal stages underpins the cultural separation of different generations. A report by United for All Ages (2020) argues that the UK is one of the most age-segregated countries in the world. The authors identify very little intergenerational contact outside peoples’ own families and relate these divisions to a culture of ageism. It is no wonder that culture embodied through artefacts designed for older people is often starkly different to those designed for younger adults. But at what age does ‘old age’ begin? De Beauvoir (1996) refers to the great philosophers who deemed that we reach our highest point of development in the middle of our lives: Hippocrates thought it was at 56; Aristotle thought the body attained perfection at 35 and the soul at 50; Dante thought old age began to be felt at 45. In the latter part of the 20th century, most modern industrial societies retired their workers at the age of 65. Now, in the UK, workers aged 65 and older will make up more than half of all employment growth between 2020 and 2030, and nearly two-thirds of employment growth by 2060 (Hill 2019). This trend challenges traditional narratives of old age and retirement, and perhaps reflects the economic constraints many older people face that compels them to remain in paid employment. With the average age of hip fracture at 77 (National Institute for Health and Care Excellence 2023), it also demonstrates that a significant proportion of the workforce will be at higher risk. This further reinforces the opportunity to develop hip protector products that reflect the needs and lifestyle aspirations of active older generations.

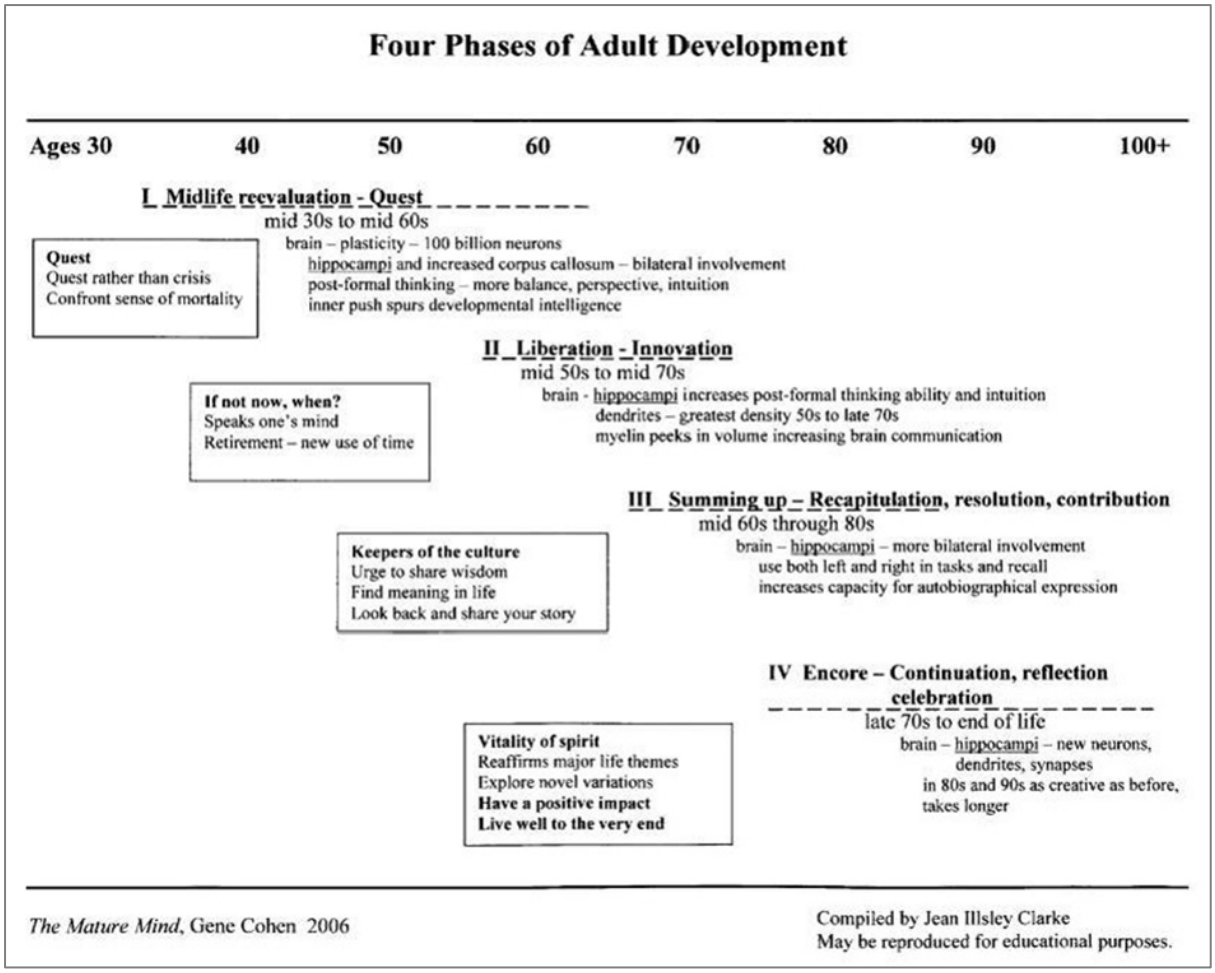


Figure 1: Illsey Clarke. 2013. Gene Cohen's 'Four phases of adult development'.

Psychologists, such as Erikson (1963), have theorised the different stages of the life course, attempting to map psychosocial development from childhood to old age. More recently, Cohen (2006) has explored the psychology of old age within the wider context of adult development, determining age should not be a barrier to living creative and meaningful lives (see Figure 1).

His framework has four phases starting from a midlife revaluation, or 'quest', and builds to a final 'encore' phase, living well to the very end. Counter to Erikson's framework that leads to a final life stage of 'integrity versus despair' (negotiating feelings of satisfaction and happiness or experiencing a deep sense of regret), the language used in Cohen's approach reflects positive attitudes towards ageing and views it as a holistic part of adult life. This is a useful tool when considering hip protector users, different contexts and scenarios of use. For example, people living in the final 'encore' phase may have different product needs and desires compared to a person in the 'liberation' phase who may be at risk because of osteoporosis. Cohen's framework will be returned to later as a tool to map the life stages of potential hip protector users.

Although the baby boomer generation were pegged to re-write the rules on ageing, negative attitudes towards old age remain culturally engrained. Research into the social and cultural ramifications of ageing, and the lived experience of being an older person, is a relatively recent field. Using critical gerontology as an approach to underpin hip protector design, an opportunity to challenge ageist attitudes can be mediated through the development of new products that reflect positive messages about ageing. This can be done through an understanding of the meaning-making aspects of design and the theory of fashion as communication.

2.1.2 Clothing semiotics

Hip protector garments (especially underwear hip protectors) are positioned within a medical care context, typically sourced in the UK through suppliers such as Mobility Smart, Medipost and Betterlife (part of the Lloyds Pharmacy group), who provide a wide range of care-related products. However, this is at odds with the practical reality of these products as items of clothing, worn within daily routines. The clothes we wear can reflect our personal identity, sense of self, and how we 'fit in' with others. Designing a hip protector that meets a user's psychological needs is rooted within understanding the meanings they convey. An ambition for this PhD research project is to normalise the use of hip protectors so they are perceived as regular clothing. In that scenario, they would be subjected to the same visceral judgement applied when pondering the rails at a clothing retailer, i.e., how does it look and feel when I try it on? Is it 'me'? The commonly utilitarian aesthetic, lack of variation in colour and shape, and dominance of underwear style hip protectors, may all contribute to a dislike of current hip protector designs. The barriers to acceptance of hip protectors are explored in more detail later (see 2.2.3). However, wearing hip protectors may be challenging for some if the wearer does not want to *communicate* that they are vulnerable by association. To be able to design better hip protectors that reflect the socio-cultural and lifestyle aspirations of older adults, the question of what meanings are interpreted through these garments, why and how, is fundamental.

If we are to interpret meaning through the design of clothing then fashion can be understood as a form of communication, although the consistency, accuracy and depth of that communication is widely argued by fashion theorists (Davis 1992; Feinberg et al. 1992; Barnard 2002, 2007a; Campbell 2013). Barnard (2007a) notes that there are generally considered to be two notions of what communication is. Firstly, the linear process of transmitting and receiving messages, a model with its origins in the telecommunications industry (Fiske 2011). Barnard (2007a) argues this model is problematic when applied to fashion as communication as the roles of 'sender' and 'receiver' cannot

be clearly defined. "Given the fashion designers ('senders'?) already know their market and take that market's preferences into consideration, and given that it is possible that the purchaser of the garment is a potential 'receiver', there is a sense in which the receiver determines the nature of the message" (Barnard 2007a: 138).

The second notion of communication is the cultural negotiation of meanings, considered as a semiotic school of thought. Semiotics is the study of signs, how they are interpreted and how they construct meaning, investigating the ways we represent our world to ourselves and each other (Sless and Shrensky 2023). Barnard describes communication through fashion and clothing as, "a social interaction that produces or constitutes the individual as a member (or not) of a culture" (2007a: 139). The meaning is not simply a message sent to a receiver, but occurs as a result of the interaction between cultural values (ideas and beliefs) and the visual (Barnard 2007b). How the meaning is interpreted is dependent on the 'who' and the 'when'. One cultural group at a particular moment in time will construct meanings differently to another. Similarly, the intention of the wearer to communicate through their clothes, or the receiver's own understanding of the meaning, may, or may not, exist. Campbell argues that individuals may, "be aware that they are sending a message, even though it is not their intention to send one, just as they may succeed in sending a message even though they neither intend to do so nor are aware that they have done so" (2013: 349).

Roland Barthes, one of the pioneers in the study of clothing semiotics, proposed that there are three distinct structures for analysing the meaning of clothes (Barthes 1985). These are the 'technological structure' (the actual garment itself), the 'iconic structure' (the visual depiction of the garment as an image), and the 'verbal structure' (the description of the garment in words). Barthes (1985) emphasises the importance of the verbal structure, anchored in the study of language and its semiotic properties, determining that understanding how fashion is described is key to understanding its meaning. However, Barthes ideas are controversial and theorists such as Jobling (1999) challenge the lack of clarity and specificity in the analysis of his coding system, with concern for the, "semiological implications of prioritising written clothing over image-clothing" (Jobling 1999: 86). Despite this criticism, Barthes' ideas are regarded to have laid the foundation for the study of the semiotics of clothing (Owyong 2009). In this PhD study, both iconic and verbal structures will form an important part of the analysis of the meanings of hip protector garments. Although technical structures, i.e., existing hip protectors and new concept prototypes, will also be analysed, the use of images and verbal descriptions provide a practical method (due to the cost of buying hip protectors or when communicating design concepts) for understanding the meanings they convey through human-centred design research methods (see 3.2 Research methods).

Twigg (2013) observes that fashion is often presented with an emphasis on creating a unique and individual version of the self through the consumption of goods. Indeed, Barthes (1985) thesis was based on sampling from two fashion magazines, Elle and Les Jardin des Modes, between 1958 to 1959. However, Twigg (2013) argues that clothing worn to intentionally communicate self-expression and agency is largely overstated. Her research with older women in the UK demonstrated that most of their clothing choices made were based on conformity rather than wanting to stand out. "Wearing the right clothes, the appropriate dress for the occasion, fitting in rather than standing out, are the dominant concerns of most people" (Twigg 2013: 24). Wearing a hip protector garment – hardly the pinnacle of fashion to begin with – may place an individual uncomfortably outside this social construct.

Table 1: Topo and Iltanen-Tahkavuori. 2010. Features of patient clothing along the dimension of normality and otherness.

Normality, continuity	Otherness, discontinuity
Clothes…	Clothes…
• are in accordance with gender specific cultural norms of clothing	• are not in accordance with cultural norms of clothing
• protect one's privacy	• are revealing and infantilising
• conceal illness and disabilities	• highlight and stigmatise disabilities
• support or enable independence	• prevent active involvement or action
• have a familiar appearance and are aesthetically appealing	• have an "ugly" or odd appearance
• are easy to put on, pleasant to wear	• are uncomfortable to put on and to wear
• fit the wearer	• are the wrong size, do not fit the user appropriately
Signals moral competence and situational control	Signals incompetence and inability, and loss of situational control

Davis (1992) suggests that if clothing is code, then it is one with 'low-semanticity'. This is perhaps true of much of the clothing worn day-to-day by men and women. However, due to their context of use, demographic of typical user, and visual appearance, hip protectors are arguably a garment type with high semanticity. This point is reinforced by Topo and Iltanen-Tahkavuori (2010) who examined how clothes provided by hospitals and other care institutions construct a notion of 'patienthood' as

materialised ideology. Although the work looks more broadly at clothing worn by patients in care environments the principles discussed are easily applied to hip protectors. The authors argue that wearing patient clothing is a process of giving up control and identity. They reflect on the 'otherness' of patients' status that is underlined using institutional clothing. They have developed a framework to distinguish between clothes that represent normality and clothes that represent otherness (see Table 1). This is very useful when viewed with respect to hip protector design, where characteristics, such as being in accordance with cultural norms of clothing, aesthetics, usability, and comfort, all resonate with barriers to acceptance and adoption established in other literature.

This phenomenon is illustrated through the design of hip protector garments identified through the practice review. The functional attributes of the Dainese snowboarding hip protector and the HipSaver hip protector (see Figure 2) are almost identical but aesthetically they are very different. The opposing visual appearance and material selection demonstrates the difference in motivations and expectations of the designers of these products, and their perception and understanding of the users they are designing for. The visual language of the Dainese product aligns with performance sportswear, reinforcing its position as a 'garment of empowerment'. This is signalled through details such as the branded waistband, colours, and technical fabrics, which are aligned with the culture of snow sports.

(Left) Photo of snowboarding crash pants removed for copyright reasons. Copyright holder is Dainese.

(Right) Photo of hip protector underwear removed for copyright reasons. Copyright holder is Derma Saver.

Figure 2: Left, Dainese. ca.2019. Action Short Evo snowboarding crash pants. Right, DermaSaver. ca.2010. HipSaver hip protector underwear with open crotch.

The appearance of the HipSaver product, however, is arguably reflective of Topo and Iltanen-Tahkavuori's (2010) notion of clothes that signal incompetence, inability and loss of situational control. The bulky pads have an odd appearance, and the garment is not in accordance with cultural norms for underwear. Contrary to the snowboarding hip protector, the HipSaver product adopts a position of 'garment of dependency'. I am not arguing that older people at risk of accidental falls should wear snowboarding hip protectors (unless of course they are skiing or snowboarding), but that the visual language of hip protectors should align with cultural norms and the lifestyle of the wearer.

An investigation into the 'meaning making' aspects of design will underpin the development of hip protector garments that challenge existing narratives associated with both the user and the product. Fashion is a form of communication, but the clarity of the message is dependent on the wearer, context, and respective understanding of 'the language' by the receiver. The visual connection between hip protectors and medical orthoses, and the assumptions of decline and loss associated with the culture of ageing, signifies the dependency of the wearer. The 'high semanticity' of these garments is reflective of a design approach focused on solving the problem of hip fractures. By challenging this medical model of design development, new opportunities can be sought to develop hip protectors that evoke more positive, empowering meaning through inclusive design.

2.1.3 A social model for hip protector design

Inclusive design seeks to understand and prioritise the user experience. However, addressing user needs for those excluded in the design of products must extend beyond the realm of functionality and usability alone. It is also about understanding that, "the less tangible human factors – identity, emotion, delight, self-expression – are common to us all, and that getting these right for users who are vulnerable to exclusion is an effective way of ensuring that what we design really does enhance life quality, simply and intuitively, for as many people as possible" (Coleman et al. 2007: 16). It is notable from initial research that hip protectors are positioned as a medical intervention, not a consumer product, dislocated from the less tangible human factors described above. This finding reflects Pullin's (2009) recognition of the significant cultural differences found between product design and medical engineering. Assistive technologies and mainstream products are often considered separate market segments, "with assistive technology being primarily a subset of rehabilitation engineering" (Newell 2003: 173). In this respect, the discourse concerning the design of hip protectors sits firmly within literature from the fields of medicine, nursing, and gerontology.

For example, Cianferotti et al. (2015) and Laing et al. (2011), assert that aesthetic considerations, are secondary to the biomechanical properties of hip protector design. Here the primary focus is on principles of engineering relating to energy absorbing or deflecting materials that reduce the risk of hip fracture. This could be described as an assistive technology approach, primarily associated with long-term functional support (Newell 2003). Tanjil's (2016) work recognises that acceptable garment appearance is a key design criteria but ranks it as least important after other functional requirements. Watkins and Dunne (2015), whose expertise is in functional clothing design and broader classifications of protective garments, suggest a more intuitive approach:

> A garment cannot provide protection if it lies on a shelf. The designer's most difficult job is to design *acceptable* protective forms. The perfect protective garment would involve no trade-offs - it would meet an individual's physical *and* psychological needs. The ideal is often impossible to reach, so designers must work to maximise the degree to which each need can be met. (Watkins and Dunne 2015: 254)

To establish an inclusive design approach to the development of hip protectors, it is vital that the needs of users are critically understood and they are involved in the design process (Newell 2003). It must also be acknowledged that those needs will be as diverse as the users themselves. There has been a tendency to view “the elderly” as a homogenous group (Metz and Underwood 2005) for whom the risk of hip fracture is a singular problem to solve. Similarly, Pullin (2009) argues that design for disability is a field almost exclusively occupied by people from clinical and engineering backgrounds where the dominant culture is one of solving problems. Within this medical model of design development, although well meaning, there’s a tendency towards a paternalistic approach (Conway 2008). Pullin (2009) champions a social model of design development that acknowledges, not only our own perceptions of a product, but the significance of the perceptions of those around us. In seeking a more meaningful approach to the design of hip protectors, the engagement with a social model of development will be integral to this design practice-based PhD.

Phenomenology, the study of lived experience, could provide a lens through which the perception of wearing hip protector garments is explored. In The Phenomenology of Perception, (Merleau-Ponty 2012) argues that we as humans mediate all our experiences through our bodies. Perception is not an isolated event or something that just happens in our minds, but is a bodily phenomenon (Carman 2020). The sensation of, for example, garment fabrics moving over the skin, or the feeling of protective padding pressed against the hips, provides further domains of meaning to explore beyond the visual perceptions of clothing described in the earlier chapter (see 2.1.2). Can an awareness of

padding around the hips feel *reassuring*, rather than uncomfortable, distracting, or make the wearer feel self-conscious about their outward appearance? The latter negative experiences signal a disruption in the use of hip protectors. In The Semantic Turn, design theorist Klaus Krippendorff refers to the work of Martin Heidegger, a student of the German philosopher and founder of phenomenology, Edmund Husserl. "According to Heidegger, disruptions, or 'breakdowns' as he calls them, signal a change in concerns from being tacitly involved with the world to engaging it as 'equipment'" (Krippendorff 2006: 88). Heidegger observes how we are constantly involved with the world, mostly without paying much attention to our involvement. This includes at the external boundary of our bodies (motor and sensory organs and skin) but also its interior (nervous, immune, pulmonary and digestive systems) (Krippendorff 2006). He refers to this way of attending to the exterior world and its artifacts as "ready-to-hand". In contrast, disruptions render artifacts as 'equipment' and "present-to-hand" (Heidegger 1962; Krippendorff 2006).

In relation to product design, (Krippendorff 2006) uses the example of a mouse to move a cursor on a computer screen. Our focus is not on the mouse itself but on the tacit on-screen activity, making the mouse "ready-to-hand". When the cursor doesn't move as we expect, our attention shifts back to the mouse which then becomes "present-at-hand". Arguably, clothing is most comfortable when it is "ready-to-hand". When clothing becomes "present-at-hand" we may decide to make an adjustment, such as undoing a button or readjusting its position, or removing the garment altogether. It follows that hip protector garments should be able to be "ready-to-hand" and once the wearer has put it on their awareness of it on their body recedes. Discomfort caused by bulky pads, for example, will immediately render the garment "present-at-hand". This disruption may not be resolved by the wearer so must be considered in the design of the garment alongside other factors that affect comfort such as fibres, fabrics and garment construction. Although phenomenological experience could inform the design process, research ethics constraints (see 3.6) mean that older users are not permitted to wear hip protector garment prototypes. Without feedback on this lived experience from actual users, phenomenology will not be a key tenet to underpin design practice. However, other approaches to human-centred design research will be embraced.

Human-centred design methods are concerned with how users attribute meanings (Krippendorff 2006). In establishing a human-centred approach, there is a natural alignment with a social model of development. This contrasts with a technology-centred approach where, for example, emphasis is placed on the engineering of shock absorbing technologies in hip protector design, and an alignment with the medical model. Through embracing a social model, the practice will position the hip protector as a consumer product rather than solely an assistive technology. In doing so, the social, cultural, and economic barriers to the development of effective hip protection, can be given equal

prominence to the technological barriers, embracing a transdisciplinary and inclusive design approach.

Hip protectors are broadly viewed as a type of 'disability product'. In accepting that the user is at a higher risk of falling over, due to reduced mobility or frailty, the perception is that they are 'less able' than someone else who has a lower risk of falling. Pullin (2009) observes a tendency within the medical engineering profession to design wearable disability products to be as discreet as possible. This is illustrated through the miniaturisation of hearing aids or the prevalence of flesh coloured prosthetic limbs, although the preference for this style tends to come from older people (Ferrendelli 2018). In a society where these types of products are hidden, it sends a negative message that disability is something to be ashamed of. Similarly, there is an inclination to design hip protectors to be discreet, if not 'invisible'. Despite a demonstrable increase in protection, manufacturers are reluctant to develop hip protectors with thicker and wider pads which may be perceived as too bulky (Laing et al. 2011). The Bort Medical hip protector, for example, has a very low profile pad with a contour that echoes the shape of the hip and upper thigh. Its aesthetic is reminiscent of tight fitting sportswear and would be imperceptible to others when worn under clothing. However, in impact tests at 2m/s, the pad has force attenuation properties of only 0.3%. This is compared to 48.3% in the highest performing pad (Qvortrup Medical's HIPS) in the same study (Laing et al. 2011). The discretion of the product – and perhaps its comfort – is at the expense of its biomechanical efficacy.

One example of a disability product where discretion is not central to the design criteria, are spectacles. They were initially conceived as an orthotic device to correct impaired vision, but the 20th century was the turning point when glasses also became a fashion accessory (Murray and Albrechtsen 2012). Their rise in cultural acceptance and evolution into mainstream fashion, has grown the glasses market into a multi-billion dollar global industry (Lipow 2017). In 2013, 69% of people in the UK wore glasses, a rise from 62% in 2011 (The College of Optometrists 2013). It is now even commonplace for fashionistas to wear glasses without prescription lenses (Ruof 2017) or with no lenses at all (Cohen 2012), elevating their social significance, above and beyond their medical purpose. It seems remarkable that a product worn on the face is so universally accepted when so much of our personal identity is anchored to this small but significant part of the body. Reflecting this shift and absorption into fashion design, glasses have now become 'eyewear'. Pullin (2009) draws on terms well understood in the fashion industry (and frequently used in relation to eyewear), such as 'collection', 'labels' and 'brands', and how these words set up different expectations with consumers. In this respect, he also notes how 'consumers' is a long way from 'patients', or even 'users'.

Pullin (2009) presents an excellent example of medical product design that sensitively embraces both human and technology centred design approaches. The plywood leg splint designed by Charles and Ray Eames (see Figure 3) wonderfully demonstrates the interplay between medical intervention and a creatively designed product. In understanding how the visual language of hip protectors could be challenged, the leg splint is a useful example. The pragmatic requirement of the product is sensitively presented through a visual form that responds to our creative and playful sensibility. This approach is largely absent in the design of contemporary disability related products, where Pullin (2009: xv) argues, "A richer balance of problem solving and more playful exploration could open up valuable new directions."

Photo of moulded plywood leg splint removed for copyright reasons. Copyright holder is Victoria & Albert Museum.

Figure 3: Charles and Ray Eames. ca. 1942. Moulded plywood leg splint.

The positioning of hip protectors as an orthosis rather than a consumer product is reflective of the cultural differences between product design and medical engineering. In striving to develop products that most effectively protect the hip from fracture, an understanding of the psychological needs of users has often been overlooked. An inclusive design approach can overcome this by embracing a social model of research and development. Phenomenological experience could also inform the design process, but this is challenging with research ethics constraints that will not allow older participants to wear prototype hip protector garments.

In seeking a new approach to the design of hip protectors, the evolution of eyewear is a very notable case study to reflect upon. The sheer diversity of designs in terms of shape, colour, and materials, demonstrates the opportunity for hip protectors to break from a very narrow field of similar looking products to a broad range of styles, appealing to an equally wide demographic of people. In understanding the social and cultural migration from spectacles to eyewear, the case for 'hipwear' is established.

2.2 Accidental falls and hip protection

This section examines the risks of hip fracture, the availability of existing hip protector products, and barriers to their acceptance, specifically for older populations. I establish key hip protector precedents and investigate the potential for their improvement. Older people are identified as a key demographic at risk of hip fracture but younger people, especially women with conditions such as osteoporosis at risk of fragility fractures, may also benefit from hip protector garments.

2.2.1 Falls and hip fracture risk

Tideiksaar (1997) proposes three factors that can cause falls:

- Intrinsic factors, related to physiological changes as we age (e.g., degradation of muscle strength), pathological conditions (e.g., dementia), or adverse effects (e.g., dizziness) from medication.
- Extrinsic factors, such as hazardous environmental conditions, poor footwear, or faulty equipment.
- Situational factors, for example if a care giver is not available, or a fall that happens during the night.

These factors can cause falls independently or could occur simultaneously. Robinovitch et al. (2013) conducted an observational study using video capture of the circumstances of falls in care home residents. They captured 227 falls from 130 individuals and found the most frequent cause of falling was incorrect weight shifting (41%), where their centre of gravity is extended beyond the limits of their base of support. This is due to a decline in proprioceptive function that occurs with age, linked to a tendency to rely more heavily on visual information. Tideiksaar (1997) notes that very old people

will often look at the floor surface when walking or be constantly looking at the bed, chair, or toilet surface they're about to sit on when transferring. Failing eyesight can compound the risks associated with extrinsic factors such as a step or loose rug. Emerging evidence indicates the importance of the physical design of spaces to prevent falls with particular attention paid to colour contrast, floors and lighting (Department for Communities and Local Government 2008; Department of Health 2009).

More than 90% of hip fractures occur as a result of a fall (Norton et al. 1997), primarily when a person lands on their side and the impact force against the floor causes a break near the femoral neck, the section between the top of the femur and the 'ball joint' of the hip at the femoral head (see Figure 4). Sideways falls increase hip fracture risk 5-fold when compared to forward or backwards falls (Hayes et al. 1993). Crucially, however, this risk increases 32-fold when direct impact to the greater trochanter (the bony protuberance at the top of the femur) occurs (Nevitt and Cummings 1993).

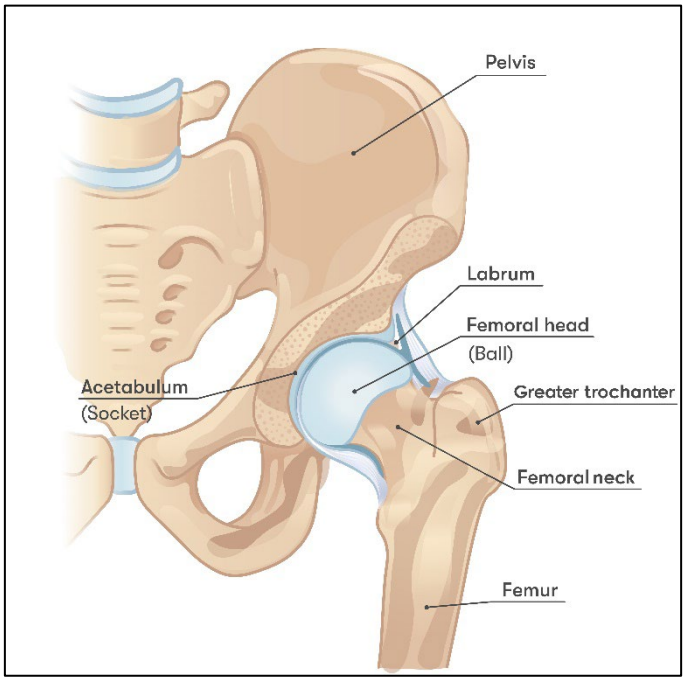


Figure 4: InjuryMap. 2019. Illustration showing the femur, greater trochanter, and femoral head.

The most significant factors that will influence the outcome of a fall causing a hip fracture are (Surgical Dressing Manufacturers Association 2021):

- The force of the impact.
- The angle of impact.

- The nature of the surface on which the person lands.
- Tissue thickness around the hip.
- Tissue density around the hip.
- Bone density (brittleness).
- Flexibility of the skeletal form.

The force of impact is the most likely to influence the outcome. The impact angle and floor surface are impossible to predict in every scenario, and the remaining points will vary from person to person (Surgical Dressing Manufacturers Association 2021).

Older residents in nursing homes, or similar long-term care facilities, are most at risk of fracturing a hip. Rubenstein et al. (1996) estimate that there are 1.5 falls per bed per year (range 0.2-3.6) in the UK. With the 450,000 beds across over 15,000 care homes registered by the Care Quality Commission (CQC), this equates to as many as 1.6 million falls per year (Hawker and Rea 2021). About 4% of these populations experience hip fracture every year (Lauritzen 1997; Chandler et al. 2000; Singh et al. 2004), which is up to 10.5 times greater than community dwelling older populations (Butler et al. 1996; Norton et al. 1999). An explanation for this trend is the tendency for long-term care residents to suffer from more chronic illness and mobility difficulties than their counterparts still living in their own homes. This is not to downplay the fall risk for people living in the community where approximately 30% of adults over the age of 65 have an accidental fall every year (Gillespie et al. 2012). Indeed, Boonen et al. (2004) show that 20% of older community dwellers who survive a hip fracture have to move to a care home because of the disability and functional impairment the fracture brings. Magaziner et al. (2000) show that among hip fracture survivors, over 80% reported needing assistance bathing or to climb five stairs at both 12 and 24 months post-fracture. Further to the chronic morbidity that can be caused by hip fractures, approximately 20% of people who experience a hip fracture die within one year of the injury occurring (Leibson et al. 2002). This is as a result of fall related complications, e.g. immobility, and the presence of acute and chronic comorbidities (Tideiksaar 1997). In 2017, the mortality rate across England, Wales and Northern Ireland, 30 days after hip fracture, was 6.9% (Royal College of Physicians 2018).

Osteoporosis is a common condition characterised by low bone mass and structural deterioration of bone tissue which puts individuals with the disease at higher risk of fractures (National Institute for Health and Care Excellence 2017). It affects one in three women and one in 12 men over the age of 50 (Department of Health 2009), although its prevalence increases significantly with age from 2% at 50 years to more than 25% at 80 years in women (National Institute for Health and Care Excellence 2017). Most fractures in older people occur as a result of falling from standing height and people

living with osteoporosis are at higher risk of these ‘fragility fractures’ (fractures resulting from mechanical forces that would not normally cause a fracture) (Department of Health 2009). Older women fall more often than men and injure themselves more frequently when they do fall (Wolfson et al. 1994; Stevens 2005). Women are statistically four times more likely to suffer a hip fracture than men (Parker et al. 2006) due to higher instances of osteoporosis and longer life expectancy. Stevens (2005) analysed a month’s worth of emergency department visits of adults aged over 65 years and found that 71% of the 22,560 patients were women. The rate of bone fracture was 2.2 times higher in women, and the hospitalisation rate for women was 1.8 times that of men. Robinovitch et al. (2009) investigated the femoral strength of cadavers and note that, "in specimens from older adults (median age = 82 years for female and 78 years for male), the median femoral strength was approximately 30% lower for female than male specimens (2,966 versus 4,220N)”. This could also account for the discrepancy in hip fracture risk between men and women. An earlier study places the average femoral strength for older women at 2,500N (Mills 1996). A German study expects that by 2050 the proportion of occurrences of hip fracture in women compared to men will reduce to 3:1. This is due to an increasingly ageing population and a projected increase of osteoporosis in men by 81% (from 1 million in 2010 to 1.9 million in 2050), compared to 40% in women (from 3.5 million in 2010 to 5 million in 2050) in Germany (Bleibler et al. 2013). A recent global study suggests that incidence of hip fracture in men will be higher than women by 2050. This is due to a smaller decline in incidence rates in men compared to women and a larger treatment gap for men (women tend to be treated for primary prevention of osteoporotic fractures, whilst men are treated for secondary prevention after they’ve had a fracture) (Sing et al. 2023).

For someone at high risk of falls, or recovering from a fall, an occupational therapist should conduct a multifactorial risk assessment and implement a range of interventions, such as a medication review and home safety assessment (National Institute for Health and Care Excellence 2013). Therapeutic exercise has been shown to be the most effective component of a multifactorial intervention (Department of Health 2009), as intrinsic factors caused by ageing, including balance impairment and muscle weakness, are the most prevalent modifiable risk factors of falls (Age UK 2013). Community-based strength training and balance classes, like those run by iCareiMove in Cornwall, UK (see 3.5), focus on falls prevention exercises that strengthen leg and ankle muscles and challenge balance. A good understanding of the types of exercises, frequency, and effectiveness at reducing fall risk is well reported (Age UK 2013). One study showed that a tailored group exercise programme delivered over nine months was able to reduce the risk of falls by up to 54% (Gillespie et al. 2012). In addition to falls prevention, both weight-bearing exercise with impact (such as walking or star jumps) and

muscle strengthening exercise are recommended to people living with osteoporosis to help maintain bone strength (Royal Osteoporosis Society 2024).

Several factors exist that can lead to falls, and the consequences of a hip fracture, especially in older age, can be devastating. Although care home residents are most at risk of falls, older people living in the community still represent a substantial proportion of fallers each year. The area most vulnerable to hip fracture risk is the greater trochanter. It is vital that hip protectors specifically protect this part of the body and are designed to accommodate anatomic variations between different users. People living with osteoporosis are at particular risk of fragility fractures resulting from a fall and this can include younger populations, especially women. Regular exercise is an important falls prevention strategy but also helps maintain bone strength. The contexts of physical activity and exercise could therefore be an important area of development for hip protector garment design. This would also help to challenge the narrative of hip protectors from a response that problematises old age to a pro-active, healthy approach to ageing and managing fall risk, centred within critical gerontology.

2.2.2 Hip protector design

Underwear hip protectors are the most commonly used garments to prevent hip fractures in older people with at least 26 different types commercially available (Laing et al. 2011). They are frequently used in hospitals and care home settings to mitigate fracture risk, often with the expectation that they are worn 24 hours a day. They typically consist of elasticated shorts that are worn over normal underwear and incontinence products when required, but open crotch styles are also available (see Figure 2 discussed in section 2.1.2) to make it easier to use the toilet. Underwear hip protectors have removable or sewn in pads that are positioned over the hip joint. Some have pads manufactured from soft, shock absorbing materials (see Figure 5), such as energy absorbing polymers like D3O (D3O 2024).

Tytex (2023) manufacture a novel ‘horseshoe’ shaped pad (see Figure 6), designed to absorb and disperse force away from the greater trochanter by not having any pad contact over this critical area. The design relies on stable positioning of the pad, as a deviation of placement over the greater trochanter would reduce the effectiveness.

Figure 5. Fall-Safe. ca.2011. Hip protector underwear shown with left hand shock absorbing pad removed from internal pocket.

Photo of an underwear hip protector garment removed for copyright reasons. Copyright holder is Tytex.

Figure 6: Tytex. ca2019. Safehip underwear hip protector with horseshoe shaped pad.

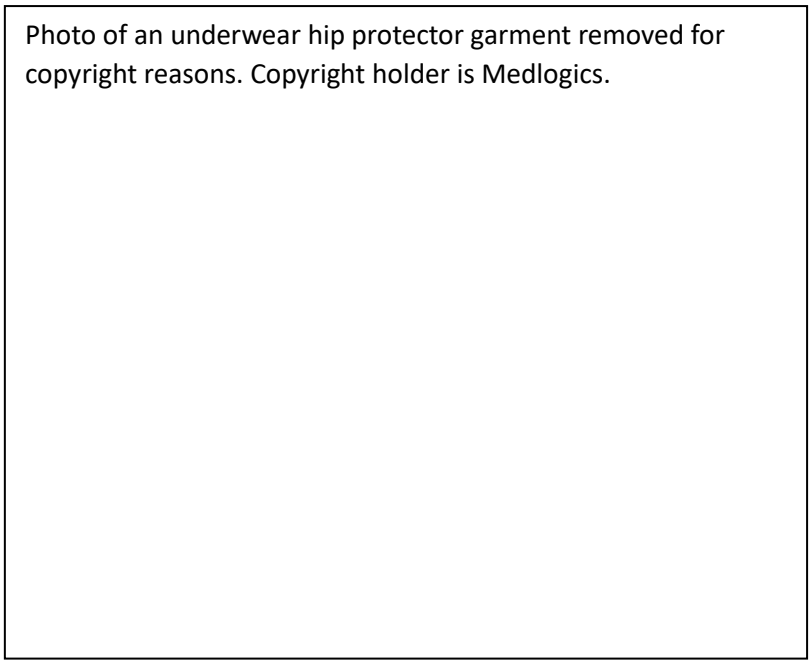


Figure 7. Medlogics. ca.2017. KPH Hip protector underwear showing hard shell pad.

Alternatively, hard shell protectors (see Figure 7), that have a dome shape to sit above the greater trochanter, are also available but not as popular as the soft pads as the rigid structure can be uncomfortable against the hip (Bulat et al. 2008; Laing et al. 2011). These are manufactured with a hard plastic outer shell with a foam inner lining. They have energy shunting properties, to deflect the impact energy from a fall away from the greater trochanter to the surrounding soft tissue.

Hip protector pads should be designed with a maximum surface area to reduce pressure over the hip (Laing and Robinovitch 2008). Based on achieving optimum positioning of the greater trochanter, Minns et al. (2007) recommend that hip protector pads should have a vertical length of more than 16cm and should be wider than 12cm. Laing et al. (2011) studied the effects of pad geometry and material properties on the biomechanical effectiveness of hip protectors (see Figure 8). They found that the hard shell pads that cupped over the greater trochanter (Caresse, Hip Guard, HIPS, KPH, and Safehip Classic) were associated with greater force attenuation at low-to-moderate impact velocities but their geometry meant that they tended to be the thickest pad type when worn (ranging from 19mm to 31mm). However, they found the soft pads were more effective at higher impact velocities due to a 'bottoming-out' of the protective bridge over the greater trochanter found with the hard shell type. The force attenuation provided by pads that contacted the skin increased with increasing pad width, thickness (ranging from 7mm to 31mm in the garment), and energy dissipation (Laing et al. 2011). It's worth noting that six of the pads tested were shorter in length or width recommended by Minns et al. (2007).

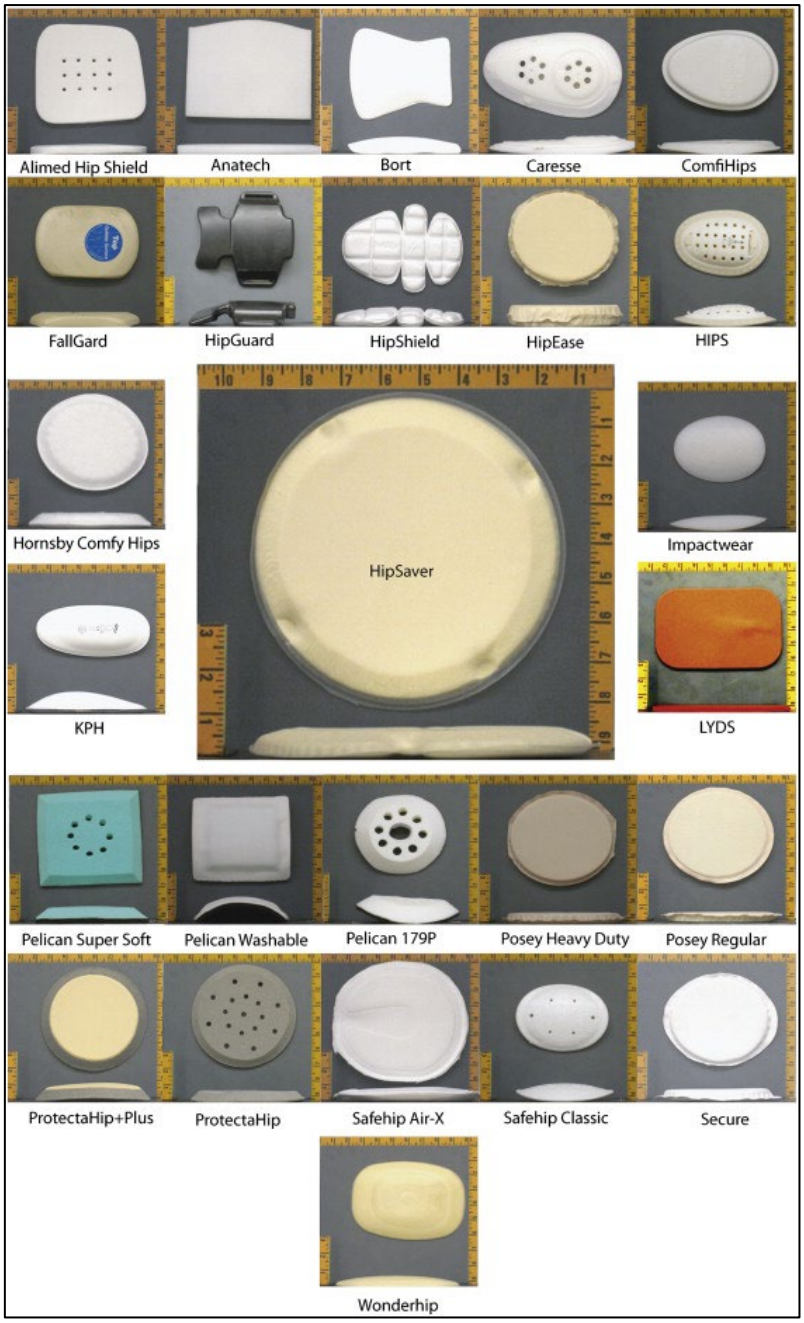


Figure 8: Laing et al. 2011. 26 commercially available hip protector pads tested for force attenuation properties. Reprinted from Journal of biomechanics, 44, LAING, Andrew C., Fabio FELDMAN, Mona JALILI and Chun Ming Jimmy TSAI, The Effects of Pad Geometry and Material Properties on the Biomechanical Effectiveness of 26 Commercially Available Hip Protectors, 2627-2635, Copyright (2011), with permission from Elsevier.

Laing et al. (2011) only investigated the protective pads, not the underwear garments. I corresponded the data from that study to images and retail costs of the actual products. I investigated these through suppliers online, ascertaining the lowest retail cost currently available (see Appendix C). There is no direct correlation between retail cost and hip protector efficacy, with

examples of lower cost products having greater biomechanical effectiveness than higher cost ones. Of the examples reviewed, the visually slimmer hip protectors, with less bulky padding, offer lower levels of impact protection than other products with thicker pads. The less bulky appearance may make the products more visually appealing, but the perceived sophistication this brings also commands a higher retail price. For example, two of the slimmer hip protectors, LYDS and WonderHips, are priced between £50 and £70 per product, representing the more expensive end of the market (compared to HipEase and Secure at around £20 to £30). Although the study by Laing et al. (2011) is over a decade old, 18 of the hip protectors are still commercially available. This demonstrates a potential lack of innovation in this market.

Figure 9. Protex. ca.2014. HiP hip protector garment worn over clothing.

Hip protectors worn over clothing are also available, consisting of a belt which extends in width over the hips, with integrated soft, energy absorbing pads. These products wrap around the body and fasten with Velcro and can be worn under clothing too if preferred. Only two examples of this type of product are commercially available: SafeHip Active by Tytex (Denmark) and HiP by Protex (Norway)

(see Figure 9). A third product, 'HipGuard', was described by Blalock et al. (2010) in a study examining factors that influence hip protector use in older adults living in the community. However, this product no longer appears available to purchase, perhaps due to low demand.

I found only one study that examined the preferences between hip protectors worn under or over clothing (Blalock et al. 2010), so further investigation into the prevalence of underwear style hip protectors is needed. Greater comfort, ease to put on and take off, less requirement for laundering, and less interference with incontinence products, seem like potential advantages to hip protectors worn over clothing. Blalock et al. (2010) compared four different designs, three of which were underwear type products, but one was the HipGuard product worn over clothing. They found that factors relating to comfort and appearance were most disliked in the product worn over clothing compared to the underwear products. Perhaps the appearance of this type of product is susceptible to greater scrutiny as it is visible when worn. The fact that it is visible at all may be the biggest issue. It may also be more uncomfortable if worn in bed, as was the expectation in this study. Further investigation is needed into attitudes towards hip protectors worn over clothing and the contexts where this style may be preferable to underwear products.

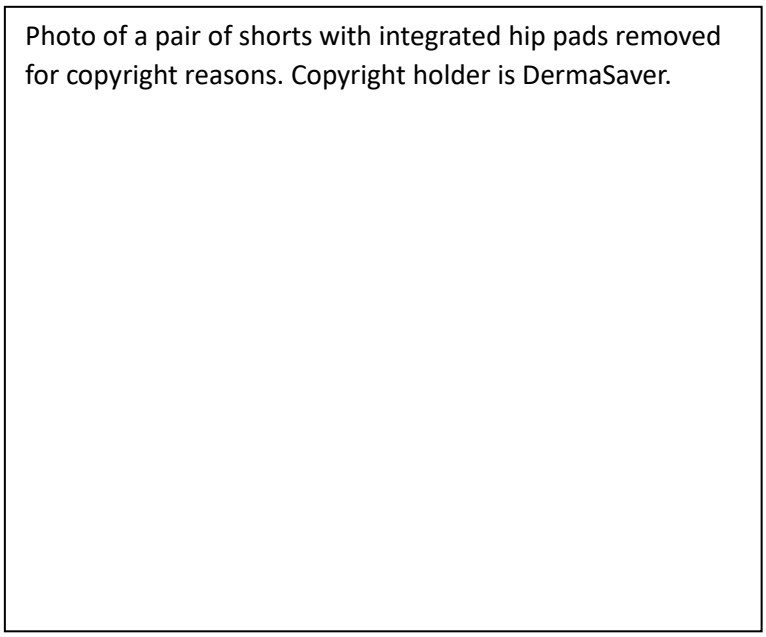


Figure 10. DermaSaver. ca.2000. HipSaver shorts with integrated hip protection.

Although padding integrated directly into clothing is common in protective sportswear (e.g., Nike Pro Combat HyperStrong shirt for American football players), this approach is not often seen in hip

protector design for older adults. Under the HipSaver brand in the U.S, DermaSaver manufacturer underwear hip protectors but also produce shorts and sweatpants with integrated hip pads (see Figure 10). Rather ambitiously, they claim that these products are, “ideal for fashion-conscious and active elders who are at risk of hip fracture” (DermaSaver 2024). They may have their place as comfortable and easy-to-wear garments, but their design is clearly driven by utility. However, the notion of integrating hip protection into everyday wear, to normalise its use and negate the need to put on and take off extra garments, is worthy of further investigation.

Hip protector pads that adhere directly onto the users skin are also in development (Minns et al. 2006; Minns 2008; Post et al. 2019). These negate the need for the pads to be integrated into a garment, such as underwear, to overcome barriers to acceptance including comfort, ease of putting on or taking off, laundering, and cost (Post et al. 2019). Initial trials of adhesive hip protector pads in an acute care setting have shown some promise in terms of usability and acceptance, with force attenuation comparable to existing pad designs (Post et al. 2019). However, concerns relating to the pad thickness and resulting visibility under clothing, and the risk of the adhesive pad damaging fragile skin, have been noted (Hall et al. 2019; Post et al. 2019).

Although underwear hip protectors are the most commonly used garments to reduce the risk of hip fracture, several barriers to their acceptance have been reported in studies and are discussed in the next section. There is no correlation between cost and efficacy of underwear hip protectors and the visually slimmer padded products tend to be more expensive but provide less protection. Hip protectors worn over clothing provide an alternative and some potential advantages compared with the underwear products. However, the limited availability of this type of product suggests a lack of demand, with their visibility when worn being a possible deterrent. Similarly, hip protection integrated into shorts or trousers represents another niche part of the market. The garments manufactured by DermaSaver negate the need for a separate hip protector product but limit the choice of clothing the user can wear. Finally, adhesive hip protector pads that stick directly onto the hip potentially overcome some usability issues but could still be perceived as ‘bulky’ and damage fragile skin.

2.2.3 Barriers to acceptance of hip protectors

In relation to the use of underwear hip protectors, six key barriers to acceptance and compliance are identified by Sims-Gould et al. (2014) that are reflected in the studies reviewed (see Table 2). Their findings broadly correspond with a similar systematic review by (Korall et al. 2015). These themes

offer key points of enquiry for further empirical research and provide useful criteria to inform a design brief for new product development. Across the studies reviewed, issues relating to discomfort, dislike of appearance and difficulty of use, are the most reported barriers to long-term acceptance.

Table 2: Six key barriers to hip protector acceptance and compliance. Expanded from Sims-Gould et al. (2014).

Key Barriers	No. of studies identified where barrier is listed	In these studies:
Discomfort	18	(Myers et al. 1995; Hubacher and Wettstein 2001; Burl et al. 2003; Patel et al. 2003; Woo et al. 2003; Doherty et al. 2004; Thompson et al. 2005; Cryer et al. 2006; Honkanen et al. 2006; Ledsham et al. 2006; Tavener-Smith and De Vet 2006; O'Halloran et al. 2007; Sawka et al. 2007; Bentzen et al. 2008a, 2008b; Blalock et al. 2010; Cameron et al. 2011; Milisen et al. 2011)
Dislike of appearance	9	(Myers et al. 1995; Chan 2000; Hubacher and Wettstein 2001; Patel et al. 2003; Forsén et al. 2004; Thompson et al. 2005; Honkanen et al. 2006; Blalock et al. 2010; Cameron et al. 2011)
Difficulty of use (getting on and off due to physical frailty)	9	(Chan 2000; Patel et al. 2003; Woo et al. 2003; Doherty et al. 2004; Forsén et al. 2004; Ledsham et al. 2006; Tavener-Smith and De Vet 2006; O'Halloran et al. 2007; Bentzen et al. 2008b)
Development of unwanted side effects such as heat rash	8	(Doherty et al. 2004; Forsén et al. 2004; Ledsham et al. 2006; Tavener-Smith and De Vet 2006; Bentzen et al. 2008a, 2008b; Blalock et al. 2010; Milisen et al. 2011)
Loss of independence, especially related to using the toilet	4	(Parkkari et al. 1998; Tavener-Smith and De Vet 2006; O'Halloran et al. 2007; Blalock et al. 2010)
A lack of understanding and acceptance of fracture risk	4	(Chan 2000; Patel et al. 2003; Doherty et al. 2004; Milisen et al. 2011)

Discomfort relates to hip protectors being generally uncomfortable to wear and unwanted side effects such as heat rash. Patel et al. (2003) found, of the 62% of women who refused to wear the

protectors for their study, the highest proportion (34%) said that it was because they were uncomfortable. Tight fitting underwear - and the potential for outer garments to feel tighter as the protective pads increase the hip width - can feel more uncomfortable sitting down, than standing up (Blalock et al. 2010). Similarly, users could be more aware of feeling the hip protectors when walking rather than at rest. Wearing hip protectors in bed might be uncomfortable, particularly if the user is trying to sleep on their side (Ledsham et al. 2006). When interviewing care home residents, Doherty et al. (2004) reported that comfort emerged as the most important consideration. They found that the hard shell protectors dug in and rubbed, causing discomfort. A resident described the hard shell as, “like a piece of plaster, a piece of a building […] it was hard and uncomfortable. It rubbed…”.

Dislike of appearance is two-fold: negative perceptions towards the overall look of the product and a dislike of personal appearance when wearing them. The fundamental requirement to protect the greater trochanter naturally requires a certain thickness of material (shock absorbing or energy shunting) to be placed over this area. The visual bulkiness of this padding certainly contributes to the dislike of personal appearance, as demonstrated through participant feedback gathered by Sims-Gould et al. (2014). In an interview, a resident commented that, “if they’re wearing slacks, they bulge out the side of the slacks, and it doesn’t look pretty”. Another resident was more scathing, adding, “It’s making you look bigger than what you are. Those things look hideous on some people”. The authors observed staff awareness of the aesthetic issues too, noting that female staff, in particular, could see the concerns for older women who felt that hip protectors made their hips look wider and overweight. Doherty et al. (2004) also noted that female care home residents were put off by the masculine appearance of underwear hip protectors, adding to the negative meanings already communicated through the garment.

Tavener-Smith and De Vet (2006) conducted in-depth interviews with hospital outpatients prescribed hip protectors, although did not state the specific type. They found the most prevalent theme was that underwear hip protectors were perceived as a garment of clothing worn within domestic routines of getting dressed, using the bathroom, and other ordinary daily activities. In this respect, physical frailty makes usage difficult. An 83 year old lady commented, “I found them very difficult to put on. I couldn’t get them up. I did manage to push them down to get them off, this is the main issue with me”. The difficulty associated with putting on and taking off hip protectors can impact on the independence and autonomy of the user. Care home residents who were otherwise able to use the toilet independently found that they couldn’t when wearing hip protectors (Ledsham et al. 2006; O’Halloran et al. 2007). Van Schoor et al. (2002) identified studies where hip protectors have actually contributed to falls for this very reason. For example, Cameron and Kurrle (1997) reported on a

woman with Alzheimer's who suffered a hip fracture after falling whilst trying to use the toilet during the night. The hip protector appeared to be around her knees at the time.

The practical aspect of underwear holding the protective pad closely to the hip cannot be ignored but the attempt to hide the protection under clothing perhaps also reflects a perceived sense of embarrassment or shame linked to ageing and loss of independence. This perception may also contribute to a lack of understanding or acceptance of fracture risk, where older people are not prepared to accept the need to wear hip protectors. Sims-Gould et al. (2014) note that even care home residents who appear frail don't recognise the need in themselves. However, they are able to recognise other residents who are very frail and unsteady and "really need them". This illustrates how hip protectors are synonymous with increased dependency and frailty for those who wear them, and naturally there is reluctance to be identified within that group. As Tavener-Smith and De Vet (2006) put it, the perception that hip protectors reduce autonomy is, "a powerful deterrent to continued use in a population where independence is paramount".

As the opportunities for inclusive design develop, this part of the contextual review underpins some key themes to explore with potential hip protector users. Protective clothing offers no protection if it is not worn, therefore receptivity is the key to eventual compliance. To foster long-term acceptance, design criteria including aesthetics, convenience, comfort and cost should be as important as the level of hip protection. The semiotics of clothing is an important consideration and greater variety may be sought, responding to an adaptive design language based on identity and context, e.g. active ager or very frail, masculine or feminine, colour, style, etc. To promote earlier adoption within 'at risk' populations, could hip protectors be seen as a positive active ageing symbol, a self-statement of independence and healthy, active living?

2.2.4 Hip protection and gender

Women are statistically at higher risk of hip fracture than men (see 2.2.1), but current hip protectors appear to overlook different gender requirements. The primary model for hip protector underwear is aesthetically and functionally aligned to masculine boxer-shorts, and this is a barrier to their acceptance. Although some designs make small concessions to gendered styling and function, many of the underwear products are sold as unisex. However, it is deeply ironic that, for a product primarily designed for a broad ageing population, many hip protectors marketed online are photographed on young, female bodies. Discourse concerning perceptions of body types, and the

notion that hip protectors on 'attractive' bodies can increase sales, is beyond the scope of this research. However, the way these products are sold brings into question who the intended purchasing audience is. Hip protector suppliers also tend to provide a wide range of care-related products selling to a wide target audience of individual consumers, but also to health care professionals and institutions. In this respect, choosing a hip protector may be out of the control of the individual who is expected to wear it, for example, purchased by a concerned relative or supplied by a care home. The loss of agency this represents could quite understandably lead to barriers to acceptance of hip protectors.

Current hip protector designs reflect what the activist and journalist, Caroline Criado-Perez, describes as the 'gender data gap'. In her book, Invisible Women: Exposing data bias in a world designed for men, she provides compelling evidence of how the design of many products assume white male universality because most other identities are so often ignored. She argues that what is male is universal is a direct consequence of the data gender gap, "but male universality is also a *cause* of the gender data gap: because women aren't seen and aren't remembered, because male data makes up the majority of what we know, what is male comes to be seen as universal" (Criado-Perez 2019: 24). She identifies some key statistics concerning falls that reflect this phenomenon, which are paraphrased here: Despite the evidence of women being at higher risk than men, gender analysis is missing from the development of fall detection, prevention and protection technologies. Thilo et al. (2016) conducted a scoping review of 53 studies that involved older people in the development of fall detection systems and found that only half described the gender of participants, offering no sex disaggregated data. Similarly, Chang and Do (2015) note that, "despite the numerous studies on falls among seniors, research incorporating gender-specific analyses is relatively scarce and limited in terms of generalizability and range of factors examined". These findings reflect a broader lack of female-centred medical research (Slawson 2019).

Katz (2015) also discusses gender, noting that it rarely figures in discourse relating to falls in older populations except where it notes that women fall more often and suffer more injuries than men. He notes several studies whereby, "the patronising double image that both naturalises women as physically weaker and more risk prone (especially after menopause) and reviles feminine strength and risk-taking as unfeminine encourages older women to see their own bodies as vulnerable" (Katz 2015: 168). It is this position that also must be challenged through a critical gerontological approach to the PhD research project.

Beyond the masculine look of hip protectors, there is further evidence that their design has overlooked female data which could put women at risk. The most significant difference between

male and female skeletons is found at the pelvis where the sacrum of the female is wider and shorter than the male, and the pelvic ring is also wider and more circular to facilitate childbirth (Jones 2022). Crucially, the mean vertical distance between the waist and the pelvis when seated (see Figure 11) is greater on women compared to men. The mean female seated waist height is 289.9mm (SD 21.9) but the male mean waist height is 286mm (SD 18.5). The mean difference may not seem significant, but the difference in waist height between the 95th percentile female and 5th male could be as much as 70mm (Department of Trade and Industry 1998). With a higher waist, it follows that the positioning of hip protector pads should be proportionately lower on a female underwear garment compared to a male one. This challenges the legitimacy and safety of hip protector garments that are sold as unisex products.

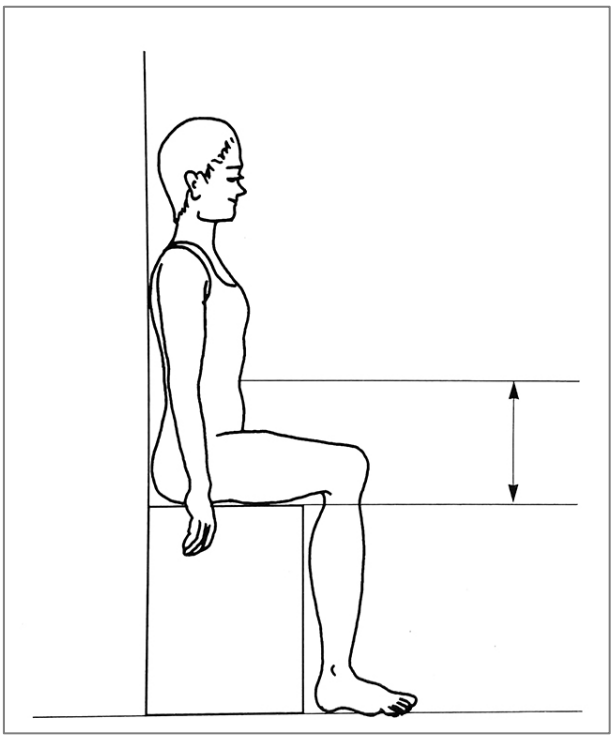


Figure 11: DTI. 1998. Waist height measured from the seat surface to the point of minimum circumference of the abdomen.

More telling, however, is a study investigating if hip protectors are correctly positioned in use. Minns et al. (2007) took measurements from female participants to determine a 'zone' of greater trochanter position and movement relative to the anterior superior iliac crest. They fabricated a removable guide that located this position on an anatomical female torso model onto which nine different hip protector garments were placed. In three out of the nine hip protectors examined, the greater trochanter position was below the bottom edge of the pad, offering no protection. Of the remaining seven, one of the hard shell type protectors only just covered the greater trochanter with

the position right on the lower edge of the shell. Similarly, for three of the soft pad type protectors, although the greater trochanter was covered, its position was below the centre of the pad. Soft shell hip protectors provide the greatest protection when they are positioned centrally over the greater trochanter (Choi et al. 2010). Due to the anatomical differences between the male and female pelvis, these discrepancies would have not been as significant had the same hip protectors been placed on male torsos.

The evidence presented here demonstrates the need for a better understanding of the physical and psychological requirements of women to inform hip protector design. Anatomically, the optimum position of hip protector pads over the greater trochanter in relation to the waist is different between men and women. The inherent masculinity of 'boxer short' style underwear and difficulty to pull up and down to use the toilet, are also barriers to acceptance for female users. However, that is not to preclude men from the process of designing more acceptable types of hip protectors. Indeed, commenting on the expected increase in male hip fractures compared to women, Sing et al. (2023) note that, "prevention, diagnosis, and treatment [of hip fractures] in males have been overlooked for years", and describe an "unmet need" to prevent hip fractures in men. Greater differentiation between hip protector garments for men and women, based on visual style, ease of use, and pelvic anatomy is clearly needed.

2.3 Wider design practice and relevant technologies

In this section, I explore broader notions of protective clothing starting with a review of protective garments and smart materials in the context of an ageing population. Fibres, fabrics and garment construction are explored in the context of intimate apparel to consider how this could translate to hip protector design. Existing impact protection materials are reviewed and the potential for digital manufacturing technologies are also discussed in relation to hip protection. I investigate further design precedents and explore the wider performance requirements that could be expected from these products. This includes an investigation into inflatable technologies for protection, an area where recent innovation in hip protector design has been seen. The practice review provides insight into how materials and technologies could be adapted and applied to the design of hip protector garments. The research presented is not exhaustive but provides a scoping review of relevant examples that will inform later design practice.

2.3.1 Protective garments and smart materials

The cross-disciplinary research project, 'Design for Ageing Well: Improving the quality of life for the ageing population using a technology enabled garment system' (Timmins and McCann 2015), is highly relevant to this PhD investigation. The project explored how the concept of the functional clothing 'layering system' could be adapted to meet the design requirements of active-agers (60-75 years). In particular, their focus was on promoting healthy exercise through the activity of walking (Timmins and McCann 2015). The sports 'layering system', adopted for outdoor exercise and leisure, comprises a moisture management base layer, mid-insulation layer(s), and a protective (i.e., from wind and rain) outer layer.

Timmins and McCann (2015: 193) also note that, "in the case of the ageing wearer, elements of personal protection (i.e., hip protectors) may be incorporated" although this did not manifest in the proof-of-concept prototype garments presented at the end of the project (McCann 2015). The project engaged co-designing principles with older users, and stakeholders from academia and industry, to develop an extensive range of garment types for both male and female users. The work responded to the demands of the ageing body (in terms of size and shape), the demands of walking as an activity, aesthetic design requirements, cultural design concerns, and commercial realities (Timmins and McCann 2015). The focus on a technology enabled garment engaged with three principles of 'smart' textiles characterised as (Van Langenhove et al. 2007; McCann 2012):

- Passive – materials able to respond to external stimulation (e.g., moisture management or impact absorption).
- Active – materials with embedded sensors and actuators that can sense and react to stimuli (e.g., user controlled heated panels).
- Very smart – materials that can sense, react, and adapt their behaviour according to environmental conditions or stimuli (e.g., accelerometers for posture positioning and activity monitoring).

The 'Design for ageing well' research led to a working definition of an attractive and functional clothing layering system, providing a basis for rapidly changing wearable electronics (Timmins and McCann 2015). The body layer garments (sports bra for women and a close fitting vest for men), included sensors to monitor the wearers vital signs (McCann 2015). The smart watch industry now dominates the market for fitness trackers that can provide basic cardiovascular health data. However, commercial wearable sensors to accurately monitor health conditions and collect useful medical data remain limited (Med-Tech 2023). Although some promising recent research has led to the

development of an electric yarn that can precisely measure body movement. The textile sensor can be integrated into clothing to detect the wearer's exhaustion level during physical exercise (Cuthbert et al. 2023). The technology could also be applied to clothing for older people to monitor anomalies in movement and predict fall risk.

Photo of Aurora power clothing removed for copyright reasons. Copyright holder is Fuseproject & Seismic.

Figure 12: Behar. 2017. Aurora power clothing.

An example of a garment for older people, demonstrating 'very smart' textile technology, is the Aurora power clothing (see Figure 12). The clothing, made from lightweight fabric, has a series of motors located over the torso, legs, hips, and back, that add 'muscle power' to aid walking, standing and climbing stairs (Morby 2017), although the actual way it works is not clearly publicised. The visual language of the garment embraces comfort, performance, and style, challenging the aesthetic of patient-scripted clothing (Topo and Iltanen-Tahkavuori 2010). However, reflecting on the barriers

to acceptance of hip protectors, ease of getting the garment on or off, especially when needing to use the toilet, and the visible bulkiness of the hexagonal motors under clothing, have clearly not been considered. A later review of inflatable technologies for protection (see 2.3.5) also relates to the field of wearable technology and smart textiles. However, the remainder of this section will explore 'passive' smart materials in relation to comfort and protection.

A visit to the international sporting goods trade fair, ISPO 2019 in Munich, provided a key source to scope contemporary design practice in protective sportswear. The show is the largest trade fair for sports business in the world, including exhibitors of products and apparel from sectors such as snow sports, outdoors, health and fitness, urban and team sports (ISPO 2024). Although the 'Design for Ageing Well' project was presented at ISPO in 2012 (with further project development presented at the later events in 2013 and 2014), the project legacy was sadly difficult to spot in 2019. No exhibitors were identified that directly addressed the 'active ageing' market and the needs of older people are seemingly still overlooked in the sportswear industry. Indeed, McCann (2016) notes that, "little record exists of sales to the ageing community, and fashion forecasting neglects the aesthetic, practical and cultural demands of what will become the new consumer majority". As one blogger put it more recently, "if you are over 60, evidently you don't exercise… or at least that's what the ads portray" (Raffelock 2023).

Figure 13: Scott USA. 2019. Airflex back protector with D3O padding

The scale of the ISPO exhibition made it difficult for one researcher to review all of the products and new technologies presented. However, there were several design examples that resonated with opportunities for developing hip protector garments. Many companies were exhibiting body armour products, particularly within the context of skiing and other extreme sports. This mostly consisted of elasticated, close fitting clothing with moulded protective foam padding that was often visible and integral to the design of the garment. For example, Scott USA's Airflex back protection (see Figure 13), uses a shock absorbing polymer developed by D3O to protect the wearer's spine. Companies such as Dainese and POC have taken similar approaches.

Figure 14: Komperdell. 2019. Hoody shirt with integrated back protection

Komperdell are an Austrian company who specialise in snow sportswear. Their 'Hoody Shirt' is an example of the same type of back protection integrated into a more casual hooded sweatshirt design (see Figure 14). The visual language of these garments embraces a technical sophistication commonly found in performance sportswear. The form, materials and detailing reflect the contexts in which they are used, embodying notions of speed, agility, and robust protection. These are garments that empower users and give them the confidence to push limits of personal safety and control. They are a far cry from DermaSaver's shorts and sweatpants (see Figure 10, section 2.2.2) where the

poorly concealed hip protector pad, the drab colours, and baggy fit, evoke a less refined visual appearance.

Manufacturers are producing hip protector garments across several different sporting industries where risk of injury is commonplace, including cycling and snow sports (e.g., G-Form, POC, Dainese, Race Face, Alpine Stars, Fox, Rippl, and O'Neal), and motorcycling (e.g., Richa, John Doe, Rukka, Klim and Revit). ArmaUrto produce protective cycling clothing with low-profile integrated padding (see Figure 15). It is made of a non-Newtonian polymer that is flexible but hardens on impact to dissipate the energy (this technology will be discussed further in section 2.3.3).

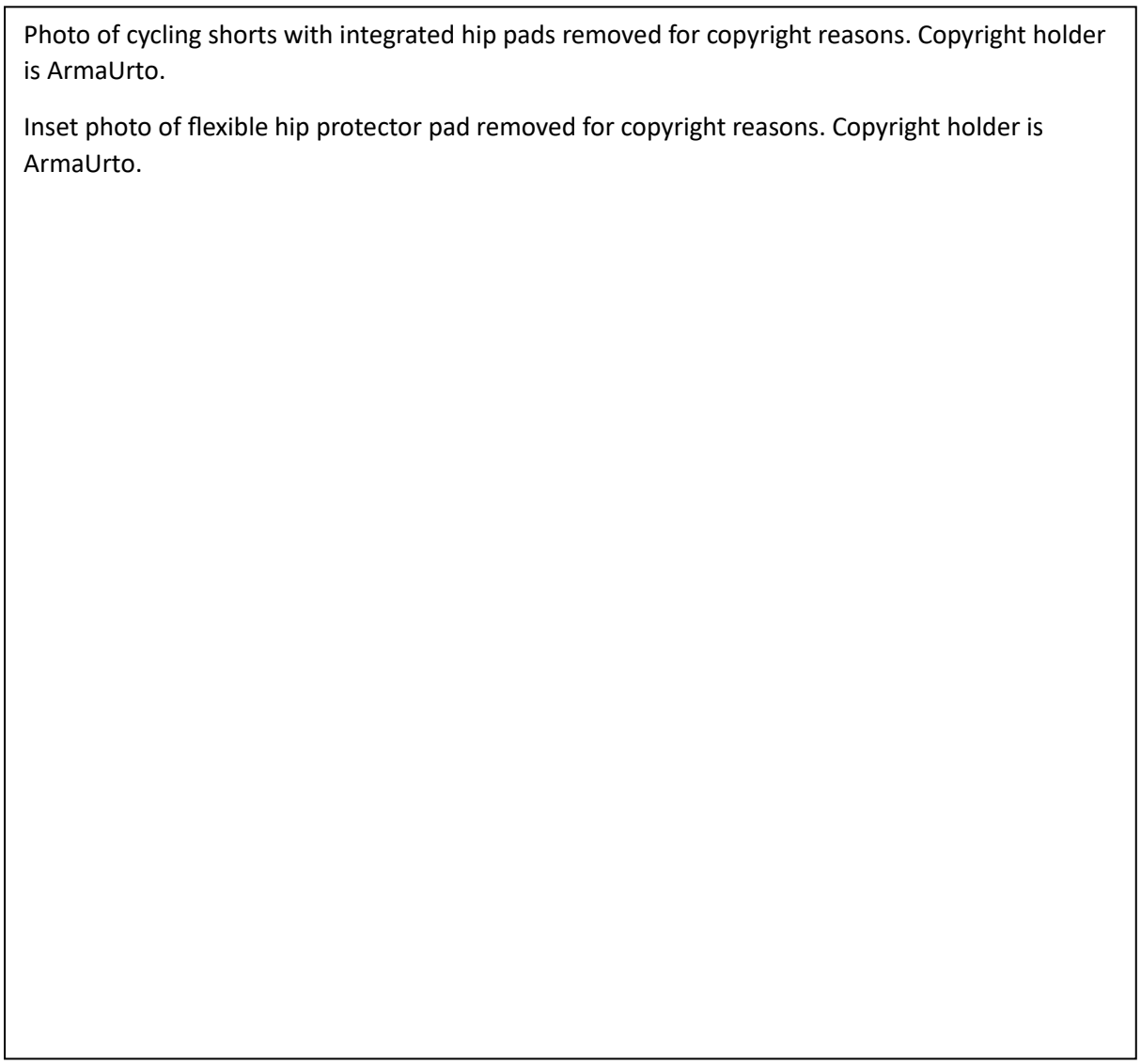


Figure 15: ArmaUrto. 2021. Cycling shorts with integrated ARMA protection over the hips. Inset image demonstrates the flexibility and thinness of the ARMA material.

They specialise in road cycling where, unlike mountain biking and snowboarding, streamlined and thin protection is paramount for race speed. The 'ARMA' protective pads, bonded within their garments, are only 4mm thick in the centre, tapering to 1mm at the edges, and weigh around 40 grams (Danailov 2023; ArmaUrto 2024). The result is a sophisticated visual appearance where the protective pads are not prominent at all. As discomfort and bulky appearance are key barriers to acceptance of hip protectors for older users, the protective material developed by ArmaUrto sounds encouraging. Indeed, the ARMA pads have passed the EN1621-1:2014 (CE level 1) standard, the test used to assess the protective qualities of armour worn on the limb joints (including hips) of motorcycle riders. However, in order to pass the standard, the mean maximum transmitted force must be below 35kN with no single test over 50kN (ArmaUrto 2021; SATRA 2024). Although ArmaUrto claim the material reduces impact forces up to 80%, they do not disclose the actual recorded values. Impact forces around 35kN are over ten times the magnitude required to cause a fractured hip in older female populations (Robinovitch et al. 2009), meaning the thin padding used in the ArmaUrto garments is unlikely to be effective protection against fragility fractures. Energy absorbing materials used in the design of protective padding will be discussed further in section 2.3.3.

The opportunity to innovate in the design of hip protectors and create a new visual language can be informed by the sportswear market. However, the needs of older people are largely overlooked by this industry, presenting an opportunity for hip protection to fulfil an unmet need in exercise wear for active-agers. Although the integration of health monitoring technologies is outside the scope of design practice for this PhD investigation, the notion of smart passive materials, with moisture management and impact absorbing qualities will be explored. Examining protective clothing outside the context of assistive technologies or orthoses reveals new perspectives on the materiality and visual appearance of existing hip protectors. This initial review provides a conceptual palette with which to challenge the function, meaning and context of use of hip protector garments.

2.3.2 Fibres, fabrics and garment construction

The close-fitting stretch fabric of the Aurora power clothing (see 2.3.1) is a necessary characteristic to keep the assistive motors pressed to the surface of the body. Indeed, the same principle can be applied to protective clothing where energy absorbing materials are held in place under stretchy fabric that hugs the body. In hip protector design, this is seen in the Safehip and KPH examples shown earlier (see Figure 6 and 7). As this is also akin to base layer and compression garments of the

sports layering system, it is worth looking more closely at the fibres, fabrics and construction used in these types of activewear and intimate apparel.

The raw materials of fabrics can be derived from natural and synthetic fibres (Senthil Kumar and Suganya 2017). According to sports apparel design and manufacturing company, Sports Casuals International (2023), the five most common fibres used in sportswear are:

- Polyester – lightweight, cheap and durable synthetic fibre that is quick drying with moisture-wicking ability.
- Elastane – synthetic fibre, also known as Spandex, with excellent stretch and recovery properties.
- Nylon – strong and durable synthetic fibre, ideal for high wear and tear applications.
- Merino wool – soft natural fibre from the merino sheep with excellent moisture-wicking properties.
- Man-made cellulosic fibres (MMCFs) – natural fibres from pulp derived from renewable sources such as eucalyptus or bamboo. MMCFs are strong and durable, have excellent moisture-wicking properties, and are quick-drying

Discomfort is the highest reported barrier to the acceptance of hip protector garments (see 2.2.3). In addition to discomfort associated with the protective pads, the fibres and fabrics used can also have a significant bearing on comfort. The most critical factor that fibres contribute towards wearer comfort is moisture and thermal balance ensuring a suitable microclimate next to the skin (Venkatraman 2016). Researchers have also explored how the skin interacts with fabric by body mapping the regional differences in skin friction, tactile perception, and sensitivity (Temel et al. 2023).

Synthetic fibres have been more widely used in activewear due to the broader performance enhancements they offer compared to natural fibres. However, optimised performance can also be achieved by blending natural and synthetic fibres. For example, cotton is used in apparel because it absorbs perspiration, but it saturates quickly, which causes discomfort as the fabric clings to the skin. So, cotton and polyester are often blended to gain comfort without cling (Venkatraman 2016). Synthetic fibres are also blended to improve performance. For example, polyester is blended with elastane to create a fabric with good stretch and recovery, commonly used in leggings, yoga pants, compression garments, and swimwear (Sports Casuals International 2023). These types of ‘second skin’ garments are useful reference points that could inform the development of new types of hip protection clothing (relating to fibres, stretch fabrics and garment construction).

Outlast are market leaders in the development of thermoregulation textile fibres (Outlast 2024a). They have incorporated phase change material (PCM) into the Outlast thermo-material fibre (see Figure 16), consisting of microencapsulated wax that can change between a solid and liquid state in response to temperature change.

A series of four images describing how Outlast technology works removed for copyright reasons. Copyright holder is Outlast.

Figure 16: Outlast. 2023. How Outlast PCM technology works shown over four phases.

The material can absorb and store surplus body heat and release excess heat back to the body, when it cools, in order to regulate the body's microclimate (Ledbury and Jenkins 2016; Outlast 2024b). Moisture wicking fibres such as polyester or merino wool manage moisture by pulling sweat away from the skin. However, Outlast's PCM fibre manages heat while controlling the production of moisture before it begins (Medifab 2023). This is a good example in the context of hip protector garments as the US based apparel manufacturer, Jockey, use Outlast's PCM fibre in their Staycool

underwear to maintain good thermal regulation and keep the wearer comfortable (Venkatraman 2016; Jockey 2024). Similarly, microencapsulation technology allows fabrics to be infused with health-giving antioxidants or aloe vera. Recently, Acabada have developed CBD infused activewear where CBD is absorbed through the skin, targeted at areas to reduce pain and inflammation (Binns 2019). In the context of an ageing population this could also be a welcomed innovation.

Merino wool is also widely used in activewear as its superfine fibres possess superior water vapour permeability and quick drying properties (Venkatraman 2016). As Merino fibres are finer than traditional wool, they feel luxurious against the skin and have the advantage of being machine washable (Hibbert 2015; Woolmark 2024a). Like the blended fibres described above, Merino can be combined with, for example, polyester to enhance the fabric performance.

Photo of a model wearing a merino wool cycling bib removed for copyright reasons. Copyright holder is Studio Eva x Carola.

Figure 17: Studio Eva x Carola. 2024. Merino wool cycling bib..

Innovative knitwear designers, Studio Eva x Carola, have recently developed a range of cyclewear using Südwolle Group's Hildago yarn, comprising 83% Merino wool and 17% Nylon knit (Woolmark 2024b). The designs were informed by body-mapping, a technique for designing activewear that

incorporates how the body moves and responds while performing the activity it was designed for (Recreational Equipment 2024). For the base layer cycling bib (see Figure 17), this informed zoned placements such as a mesh pattern knit across the torso and legs to create a raised structure for breathability but with minimum compression (Woolmark 2024b). The technique of body-mapping to define zoned placement of fabrics and energy absorbing materials is highly relevant for the design of hip protector garments. The use of Merino wool as a 100% natural, renewable and biodegradable fibre that doesn't produce microplastics, also makes it more environmentally sustainable compared to its synthetic counterparts (Woolmark 2024b). This is an attractive option to meet the requirements of the European Union's ESPR framework to curb the release of microplastics (Boniolo 2022).

Between 2022 and 2023, the production of virgin fossil-based synthetic fibres increased from 67 million tonnes to 75 million tonnes. Polyester is the most produced fibre globally, accounting for 57% of total fibre production (Textile Exchange 2024). Manufacturers such as Jersey Lomellina are producing fabrics using recycled polyester (Jersey Lomellina 2023), although it is important to note that when polyester is blended with other fibres, it is very difficult, if not impossible, to recycle (Smelik 2023). A shift to more 'environmentally friendly' fibres is achievable with man-made cellulosic fibres (MMCFs) derived from renewable natural materials such as eucalyptus or bamboo. Rayon (first produced in the 1880s as an inexpensive alternative to silk (Hibbert 2015)) Modal and Lyocell are common examples of MMCFs (Senthil Kumar and Suganya 2017). Tencel, the brand name for Lyocell manufactured by Lenzing, is one of the most popular MMCFs on the market (Sports Casuals International 2023). Tiny fibres (known as microfibrils) on the fabric surface are moisture wicking and help thermal regulation. Tencel C is particularly relevant for an older demographic (who are most at risk of hip fractures) as the fibre contains microparticles of Chitosan (Hibbert 2015). When in direct contact with the skin, the fibre provides a cell-renewing effect, acting as a moisturiser to keep the skin elastic by maintaining optimal moisture content (Hibbert 2015).

Timmins and McCann note that, "close-to-body intimate apparel and base layers are normally of knitted construction with varied structures placed around the body to aid moisture wicking and offer increased support and protection" (2015: 194). To contextualise my understanding of textile fibres in relation to knitted construction and intimate garment design I interviewed Tony Ka Yiu Wang, Managing Director of Bodywear Lab. They are a product development consultancy specialising in sportswear and intimate apparel (see Appendix D).

Wang noted three key considerations when specifying fabrics for intimate garment construction: modulus, weight, and stretch direction. The elastic modulus refers to the amount of 'give' (or

deformation) in the elasticity of a fabric. The higher the modulus value, the smaller the elastic deformation occurs (Wu et al. 2020). Wang noted that fabric with a higher modulus, “will control the body better”, creating greater compression and support. The weight of the fabric is measured in grams per square metre (GSM), so the higher the GSM the denser the fabric. Similarly, Wang recommends that a higher weighted fabric will provide greater support and body control. He gave the example of an activewear bra that would use a higher weighted fabric of between 150 GSM up to 250 GSM to provide increased support. In the context of hip protector garments, consideration of optimum fabric modulus and weight for comfort and feeling of supportive compression is important.

The attributes of fabric stretch direction were discussed with Wang in more detail. Elastomeric and mechanical stretch properties are particularly relevant to garment design for older figure types, and relate to comfort factors such as fit, support, ease of movement, as well as shape retention (Timmins and McCann 2015). Wang noted some knitted fabrics will stretch more in one direction than the other, and how you place the direction of stretch on the body will affect the fit and performance of the garment. A general approach from a contour perspective, such as swimwear or leggings, is for the stretch to run horizontally around the body to ease putting on or removing the garment. Wang illustrated this point by describing two leggings, identical in circumference, where one has the stretch direction horizontally and the other has it vertically. With the latter, the fabric would stretch in the same direction you would pull when putting on or removing the garment, requiring more effort to move up or down the leg than with the horizontal stretch direction. In terms of ease of putting on or taking off a hip protector garment, it follows that it would be better for the fabric stretch direction to be orientated horizontally, across the body. It is important that the degree and direction of stretch offer the necessary support to address changes to body shape with advancing age. This includes a thickening of the waistline as the ratio of body fat to muscle changes (McCann 2012).

The development of 3D knitting technology has created the opportunity for seamless knitted garments that can conform to the three-dimensional shape of the body (Brownbridge 2016). Shima Seiki are market leaders in the production of 3D knitting machines. 3D knitted patterns are produced from these machines that already take the shape of the wearer, rather than being cut and stitched to shape (Shima Seiki 2024). The technology is responsible for the explosion in the design of athletic trainers with knitted uppers (Textile Today 2019). Activewear using seamless knitted construction can enhance both comfort and aesthetics. For example, sensorial comfort is enhanced because the lack of seams eliminates the risk of seam abrasion and rubbing against sensitive areas of skin. Similarly, ergonomic comfort can be improved as a seamless structure is able to stretch and move with the shape of the body more effectively than a knitted garment with seams (Brownbridge 2016).

The context of seamless knitted compression garments overlaps sportswear and healthcare applications. Timmins and McCann note, “compression garments assist blood circulation and are commonly recommended for athletes, surgical patients, oedema patients, and those with a sedentary lifestyle” (2015: 195). The William Lee Innovation Centre (WLIC) has created the Scan2Knit system based on Shima Seiki technology. They have used 3D body scan data to inform the design of compression stockings used by people who have developed severe ulcers from age, infection or injury. A bespoke stocking can be manufactured using the 3D knitting technique that accurately applies the most effective pressure profile to the leg (McCann 2012). Compression garments have also been shown to improve proprioceptive feedback (Robinovitch and Cronin 1999; Finlayson et al. 2018). The potential application of this technology – including 3D body scanning – for bespoke falls prevention garments is worthy of further investigation.

This part of the contextual review demonstrates the vast range of fibres and associated fabrics that can be specified for activewear garments. A wide range of options could be translated into the design of hip protector garments, focusing on fabrics that regulate moisture and temperature against the skin, and fibres with health giving properties, such as those infused with aloe vera. Aligning with the EU’s ESPR, careful attention should be given to the sustainability of fabrics specified, especially considering opportunities for fabrics derived from natural fibres such as merino wool or MMCFs. The construction of hip protector garments must consider the stretch direction of fabrics and how this might impact on performance, offering support for different body types, and ease of getting on and off. The potential for seamless construction and 3D knitting technologies is another important area that could be explored to enhance the comfort and aesthetics of new forms of hip protector garments. The design practice explored throughout this PhD will be constrained by a limited materials budget and access to equipment and expertise. So, these aspects of fibres, fabrics and garment construction will be explored where practically possible but could also form part of later work after proof-of-concept designs have been developed through the PhD.

2.3.3 Energy absorbing materials and approaches

Before the twentieth century, protective clothing generally served only two purposes: protection from climatic conditions, or as protective armour (Watkins 1995). One of the world’s most comprehensive collections of Japanese art and design, including fifteenth century armour, is at the V&A Museum, in London (Victoria and Albert Museum 2024). The suit of armour in the ō-yoroi style (see Figure 18) comprises of small plates of lacquered leather laced together in rows. This provided

protection whilst affording some flexibility for fighting from horseback with a sword or bow. The combination of effective protection, practicality of use, and visually pleasing detailing are key lessons to be learnt for designing hip protection in this century.

Figure 18: Unknown maker. ca. 1400-1500. Suit of armour in ō-yoroi style

The principle of ‘shingling’, where the leather plates overlap, is advantageous in terms of spreading impact forces. The impact force to any single leather plate is spread to each plate it touches, then is passed on again to every further plate the second layer of plates touch, and so on. Watkins (1995) describes the result as, “much the same in terms of spreading of force (and thus alleviating the effects of pressure in any one area) as if a solid armour plate had been used, yet the protector's capacity for movement is considerably improved” (Watkins 1995: 125).

Shingling is also similar to ‘segmenting’, where the protective material is segmented into sections to increase flexibility and help it conform to the shape of the body more effectively (Watkins 1995). The simplest method of segmenting is to cut part way through the protective material leaving a thinner layer at its base. Segmenting is demonstrated on the shoulder pad of the Canterbury protective shirt (see Figure 19), although the pad is presumably moulded into this shape.

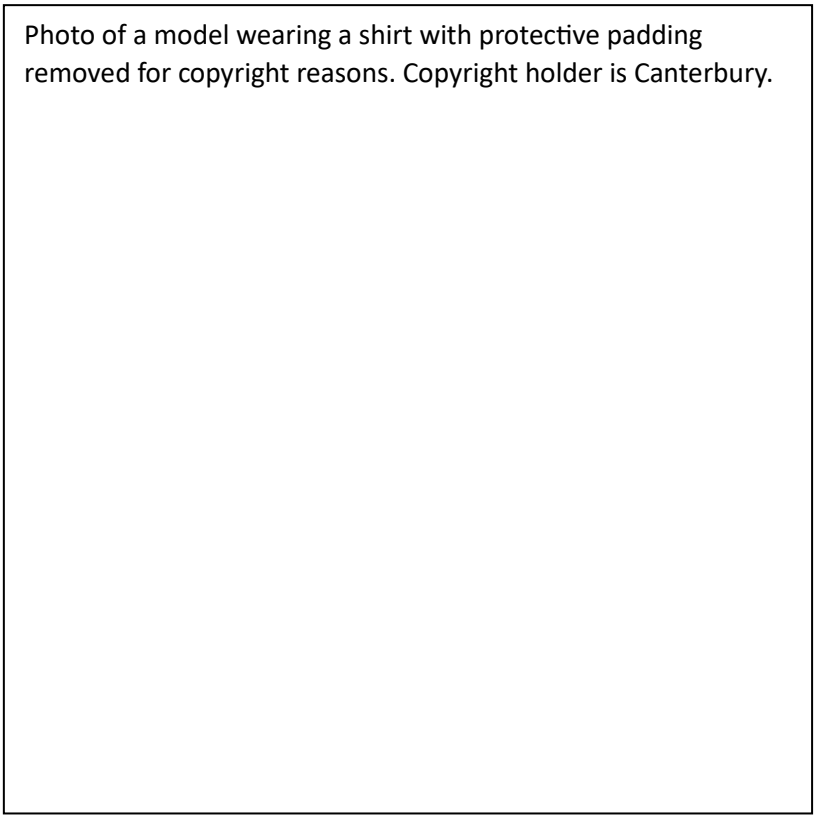


Figure 19: Canterbury. 2024. Adult unisex CCC protection vest with laminated foam padding on the shoulders.

A final noteworthy design approach is ‘cupping’ or ‘bridging’ where a rigid protective element is shaped to cup or bridge over the body area to be protected (Watkins 1995). The rigid material will often have a softer foam lining for comfort against the body. The technique allows impact energies to be both absorbed by the protective materials and shunted away from the vulnerable area. This approach is used with ‘hard shell’ hip protectors, such as the Medlogics KPH hip protector underwear discussed earlier (see 2.2.2).

Several examples of energy absorbing materials are already used in protective clothing, either on their own or combined with rigid materials, using the approaches described above. No safety standards exist for the design and performance of hip protectors (Surgical Dressing Manufacturers Association 2021). However, there is consensus on the recommendations for their biomechanical testing (Robinovitch et al. 2009). Tyler and Venkatraman (2012) conducted physical tests to determine the force attenuation properties of energy absorbing materials. Their findings aligned with other studies (Laing et al. 2011; Keenan and Evans 2019): the thicker the material, the greater the

force attenuation. The flexible polymers that harden on impact also appear to perform the best overall. The materials reviewed in this section are summarised in Table 3.

Table 3: Summary of energy absorbing materials reviewed.

Material name	Material type	Properties	Example hip protector use
EVA and PE foam	Cross-linked, closed cell polyurethane foam	Soft and flexible. Impact energy absorbed through cells	Safehip by Tytex
Poron XRD	Open cell urethane foam	Softer and more flexible than closed cell foam. Hardens on impact optimising ability to absorb energy	HiP by Protex
D3O	Polyurethane blended with dilatant (PBDMS)	Flexible material that hardens on impact optimising ability to absorb energy	Fall Safe by Medical Protection Technologies
Armourgel	Polyurethane blended with dilatant (PBDMS) moulded into auxetic cell structure	Flexible material that hardens on impact. Auxetic structure pulls material towards the impact site allowing for a reduced material thickness during resting state	Prototype development with The University of Sheffield's Centre for Assistive Technology and Healthcare (CATCH)
Baltex XD	3D knitted spacer fabric	Open knitted structure. Impact energy absorbed through sandwich layer construction	NA

Cross-linked, closed cell polyurethane foam, such as ethylene vinyl acetate (EVA) or polyethylene (PE) foam, is frequently laminated into sportswear garments to provide protection against collisions and impact, e.g. Canterbury (see Figure 19) and Kooga protective shirts (Tyler and Venkatraman 2012). Although EVA and PE foam is extensively used in protective garment applications, it is not as effective as other materials of the same thickness in terms of shock absorption (Tyler and Venkatraman 2012). PE foam is used in some soft pad hip protectors, including Tytex's novel horseshoe design on their Safehip protectors (Tytex 2024), discussed in section 2.2.2.

Poron XRD is an open cell urethane manufactured by Rogers Corporation who claim it can absorb up to 90% of intense impact force (Rogers Corporation 2024). Open cell foams are softer and more flexible than closed cell foams. When a sudden impact force is applied to Poron XRD it reacts by a rapid drop in glass transition temperature (Tyler and Venkatraman 2012). The glass transition temperature (T_g) of a polymer is the temperature, below which its physical properties change from being flexible and rubbery, to those of a crystalline, or 'glassy' state (Ebnesajjad 2016: xix). Above the glass transition temperature, the urethane molecules of Poron XRD are soft and flexible. On impact, when the glass transition temperature drops, the urethane molecules stiffen, optimising the material's ability to absorb the shock. Poron XRD is used in a variety of industries for shock absorbing and vibration damping applications. It is also used by Protex in the design of their HiP protector garment which was developed in collaboration with the Norwegian research institution, SINTEF (Protex 2023). This product is shown in Figure 9 in section 2.2.2.

UK based D3O are market leaders in shock absorbing polymers who have grown a strong brand through the development of their propriety material of the same name. D3O is made of polyurethane that also contains several additives and the non-Newtonian fluid (known also as a dilatant), polyborodimethylsiloxane (PBDMS) (Palmer and Green 2010). The viscosity of non-Newtonian fluids varies depending on the forces they are subjected to, resulting in D3O being a flexible material that becomes rigid on impact. The material is used in protective garments for sports, motorcycling, defence, and work wear industries. Its distinctive orange colour makes the brand recognisable across different applications and industries. The material is clearly visible in Scott USA's Airflex back protector, for example, discussed in section 2.3.1. Medical Protection Technologies, in the US, were the first company to use D3O for the pads in their Fall-Safe hip protectors (Medical Protection Technologies 2014).

Armourgel is also a viscoelastic polymer, blended with PBDMS, that has similar properties to D30. However, the material is moulded with a geometric cell structure that has auxetic properties (Reuters 2014). Auxetic (or negative Poisson's ratio) materials, counter-intuitively, expand laterally when they are stretched axially, i.e. they get thicker when they are stretched (University of Exeter 2024). When an impact force is exerted onto Armourgel, its non-Newtonian properties cause the flexible polymer to momentarily stiffen, helping to absorb and disperse the energy. However, its auxetic geometry also means that the force pulls the material into the impact site rather than spreading it apart. This affords a thinner and lighter material compared to other viscoelastic polymers. The same principle appears to have been applied to ArmaUrto's protective pad design (see previous section), although the company do not explicitly state this in any marketing information.

Similarly to D3O, Armourgel has been developed for use in hip protectors for older adults. Armourgel Medical Ltd partnered with The University of Sheffield's Centre for Assistive Technology and Healthcare (CATCH) to work with care home residents to co-design the hip protectors and test adherence and feasibility with a prototype (The University of Sheffield 2022). Easton et al. (2017) studied 31 participants across twelve care home locations and found that compliance rates were lower than they had hoped. The hip protector design consisted of an underwear garment much like existing products on the market. The low acceptance of these prototypes is indicative that receptivity is not related to the technical performance of the protector pads alone and designers must take more holistic approaches to develop acceptable forms of protection.

Baltex are a leading manufacturer of 3D knitted spacer fabrics. Their XD range is produced in thickness from 3mm to 20mm and is widely used as a replacement material for foam and neoprene products. The material can be knitted with different fibres on different faces to develop bespoke textiles for specific applications. They have an open structure so they are breathable and can be easily integrated into other textile elements that the garment is comprised of. XD spacer fabrics are used in many shock absorbing applications, including cycle helmets, boot soles and body armour (Baltex 2024). However, the force attenuation properties of spacer fabrics is not very well investigated. Neale et al. (2019) note key factors that hinder their development for industry including: lack of understanding of the relationship between weave variations and mechanical properties; high initial investment in loom equipment; and the length of time it takes to initially set up the loom or change the loom setup.

The review of energy absorbing materials demonstrates a variety of options that could be explored in the development of new hip protector garments. Although all the materials can help protect against impact forces, the trade-offs between comfort, flexibility, breathability, weight, and cost need further analysis. Most of the examples discussed have already been applied to underwear hip protectors. Persistent barriers to the acceptance of underwear products therefore raises this question: Should more emphasis be placed on developing the right kind of garment, rather than just specifying the most effective shock absorbing materials?

2.3.4 Opportunities for 3D scanning and 3D printing

Digital manufacturing technologies, including 3D printing and 3D scanning are increasingly being used in the production of clothing and footwear. The 3D printed wearable market (in 2023) is worth

over US$4 billion but is expected to grow to over US$10 billion by 2033 (Future Market Insights 2023). The fashion industry, however, is notoriously impactful on the environment. For example, in 2015, greenhouse gas emissions totalled 1.2 billion tonnes of carbon dioxide (and equivalent harmful gases) through textiles production, that's more than the emissions from all international flights and maritime shipping combined (Ellen MacArthur Foundation 2017). 3D printed textiles have the potential to be more sustainable through a reduction in cut-off and waste material, easier recycling of materials, and a reduction in raw materials (Buckley 2023). Engaging with these technologies reflects the EU's ESPR framework, relating to product performance and ecodesign requirements (European Commission 2024).

In the design of current hip protectors, the garment and the protective pads exist as two separate and distinct components. 3D printing technologies have the potential to bridge that divide and generate garments with closer integration of these material types. Advantages of a more holistic approach could include better control for the development of bespoke garments and improving overall comfort and fit. However, in terms of the life-cycle of the garment, the ease of which mono-material products can be upcycled has significant benefits as we move to a circular economy (Ellen MacArthur Foundation 2018). This is one of the advantages described by the makers of Modeclix, a recyclable 3D printed textile. "The ingenuity of Modeclix is that it is possible to turn a Modeclix dress into bags, hats and accessories and then back into a dress again" (Modeclix 2024). Modeclix consists of a linking nylon component that can be 3D printed in sheets and then linked to other sheets to scale up in size. Links can be detached or re-attached by hand in the desired pattern resulting in garments reminiscent of a lightweight chainmail. The translucency of the garments may limit the applications for clothing but the combination of bespoke fit, breathability, and potential for combining with impact absorbing 3D printed elements, presents an opportunity for innovation within the design of hip protectors.

There are several other examples of 3D printed garments, most notably by designers such as Danit Peleg, Anouk Wipprecht, Julia Daviy, Travis Fitch, and Alexis Walsh (Sculpteo 2023). Much of this work is in the domain of fashion catwalks and haute couture, rather than practical and wearable clothing. Yuima Nakazato's work explores a combination of textiles and 3D printed elements. His Freedom collection explores a future where bespoke garments are manufactured from individual fabric tiles that are joined sequentially using soft 3D printed connectors (see Figure 20). The geometry of each tile is digitally generated from the shape of the person who will wear the garment, ensuring a perfect fit. A variety of tiles, in different materials, can be composed to provide unique garments with aesthetic and performance requirements unique to the user (Nakazato 2017).

Although Nakazato's work does not specifically explore protective clothing, it provides an interesting conceptual starting point for bespoke hip protector garments.

Figure 20: Nakazato. 2017. Garment assembled with 3D printed connectors.

3D body scanning is another technique to help develop bespoke fitting garments by obtaining digital anthropometric data of individual users. It allows for a greater depth of analysis regarding the body and clothing compared to traditional measurement methods (Gill 2016). For example, the Size UK database comprises anonymised 3D body scans of 11,000 participants representing the UK male and female population from the ages of 16 to 95 (Bougourd 2015). The database was used to support an understanding of the size, shape, and posture of 60 to 75 year old walkers recruited for the 'Design for ageing well' research project discussed in section 2.3.1. This approach responded to the lack of representation of older body shapes offered through standard 'ready to wear' sizing, recognising that it is, "knowledge of body shape and distribution of body tissue that remains the basis for producing well-fitting clothes" (Bougourd 2015: 156). Body scanning provides a snapshot of an individual's body shape in a fixed posed that can be used to create a 3D computer representation called an avatar (Gill 2016). Using Parametric Pattern Generation (PPG) software such as CLO (clo3d.com), Optitex (optitex.com) or Browzwear (browzwear.com), garment pattern blocks can be generated based on the 3D body morphology of the avatar. The physical properties of the fabric, such as the elastic

modulus, weight, and stretch direction can be simulated in the software allowing for the virtual fitting of garments and evaluation of fit using tension maps. This allows for garment customisation responding to the variation in body shape, size and posture during the life span.

The opportunity for personalised clothing, or designs that are customised to an individual's body shape, are also exciting ways 3D printing and 3D scanning technologies are synthesising. For example, US design studio, Nervous System, use 3D body scan data to direct the size and shape of their Kinematic dress which is 3D printed as a single folded piece and requires no assembly (Nervous System 2014). Artec 3D are a global leader in handheld and portable 3D scanners. The Artec Eva uses structured light 3D scanning technology to map a physical object and generate accurate 3D CAD data (Artec 3D 2024). Portable 3D scanners are used in healthcare to develop orthotic devices and prosthetics based on the users' actual anatomy. Ortema demonstrated this technology at ISPO 2019, through the production of bespoke knee braces from a 3D scan of the user's knee. They use Captiva scanning software on an iPad to generate the 3D data used to manufacture a foam 'last' of the knee with a 4-axis CNC mill. Carbon fibre is wrapped around this form and then trimmed to create the two parts of the knee brace. Following this principle, 3D scan data could be captured to develop bespoke hip protectors that provide optimum impact protection for individual users.

Figure 21: Adidas. 2018. Futurecraft running shoe with 3D printed lattice midsole.

Adidas used 3D scan data to generate bespoke footwear for their Futurecraft 4D project (Carbon 2017). They partnered with Carbon, whose Digital Light Synthesis 3D printing technology was used to create the midsole of the Futurecraft 4D running shoe (see Figure 21). The lattice structure has auxetic properties providing different levels of cushioning and stability across the midsole (Howarth 2017). A 3D scan of the wearer's foot, as well as their height, weight and gait, can be used to precisely programme the lattice geometry so that the sole can be 3D printed to suit their specific needs. Other sports footwear manufacturers producing 3D printed midsoles are New Balance, with their 990 Sport Triple Cell and FuelCell Echo Triple (Formlabs 2024a), and Under Armour with the Architect training shoe (Tucker 2016).

The impact absorbing qualities of flexible 3D printed lattice structures in athletic trainers could also be explored as a viable alternative to traditional foam hip protector pads. Indeed, 3D scan data to optimise the size and shape of the pad, and other criteria such as an individual's bone density, could be used to develop personalised hip protection. This approach has been adopted for the design of American Football helmets to create a customised fit for the wearer (Zelinski 2023).

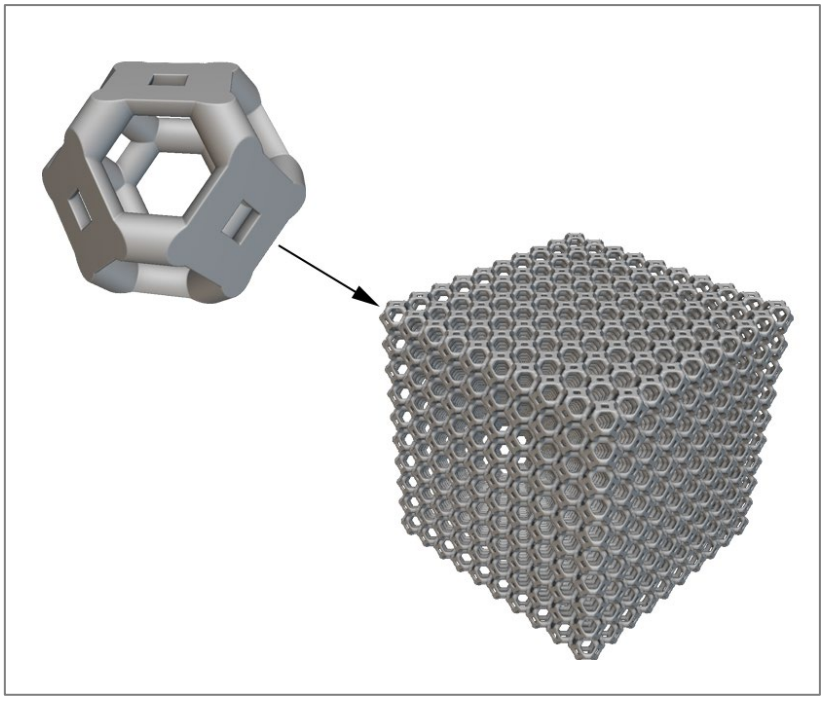


Figure 22: A Kelvin cell and lattice structure formed of Kelvin cells.

The literature exploring the development of impact absorbing 3D printed structures is growing rapidly. In establishing a methodology for generating lattice structures based on the structure of

polymeric foams, Brennan-Craddock et al. (2012) note the suitability (and extensive use in scientific studies) of the 'Kelvin cell' to simulate foam behaviour. In 1887, Thompson (later Lord Kelvin) investigated the minimum surface qualities of aqueous foams and devised, "a repeatable unit cell for a perfectly ordered, regular foam" (Brennan-Craddock et al. 2012). The Kelvin cell is a polyhedron composed of six square and eight hexagonal faces (see Figure 22).

Habib (2020) also demonstrates the viability of 3D printed impact absorbing lattices comprising of Kelvin cells. This work is of particular interest as it considers the application to hip protection. Although effective force attenuation properties are demonstrated through test samples, the main body of the research was conducted on cellular structures made from rigid plastic, at a thickness of 20mm. The stiffness and bulkiness of hip pads designed this way would make them an impractical solution given the barriers to acceptance of hip protectors discussed earlier. Similarly, Yahaya et al. (2021) explored rigid 3D printed materials as hip protection but in solid form – following the principle of a 'hard shell' energy shunting hip protector – not as a lattice structure. Both these studies demonstrate a rigorous scientific investigation but do not engage with the human-centred design approaches that will be undertaken in this practice-based PhD design project.

Isaac and Duddeck (2022) have reviewed current trends in 3D printed energy absorbing structures and note that biomimicry is one of the most promising subjects of research in this area. For example, the hierarchical cellular structure in the peel of the pomelo fruit protects it from bruising when it falls from the tree (AskNature 2016). This principle is investigated by Dwyer et al. (2023) who explore the impact performance of 3D printed Kelvin cell lattice structures. They experimented with a vertically-graded lattice structure where the cell strut thickness uniformly decreases from the top to bottom, reflecting the hierarchical nature of the pomelo skin. They also found that hybrid configurations of lattice materials, combining a harder material with a softer material, showed promising results applicable to personal protective equipment.

Park et al. (2019) also used a hybrid approach to the hip pad design, lining foam over a flexible 3D printed structure comprised of a diamond shaped mesh surface layer with a V-shaped spacer layer. They used 3D scanning to capture the user's body shape to directly inform the pad design. In this study, the researchers paid more attention to the acceptance and wearability of the hip protector garment and integrated the padding into a tailored pair of trousers. The result is a much more refined appearance than the Dermasaver shorts (see Figure 10 in section 2.2.2) but potentially restricts the user's wardrobe when using hip protection. The authors do, however, note that the concept could be developed across various types of protective clothing.

3D printed textiles have the potential to be more sustainable than traditional garment manufacturing processes by reducing waste and making recycling easier. However, much of the 3D printed clothing being produced is the preserve of fashion catwalks and doesn't reflect the practical and comfort requirements for hip protector garments. The potential for digital tools to capture body data and manufacture custom designed hip protector garments is demonstrated through this research. 3D printing technology could be used to develop hip protectors that fit better, integrating with other performance materials, as is seen with recent innovations in sports footwear. 3D printed impact absorbing materials, using flexible lattice structures, could also present opportunities to innovate, functionally and aesthetically, through closer integration of the garment and protective padding.

2.3.5 Inflatable technologies for protection

The number of published studies investigating the development of fall detection systems that operate through wearable technology has increased rapidly over the past decade (Chen et al. 2022). These can accurately detect an imminent fall or if a person's usual body movements have changed, indicating they may be at higher risk of falling. These devices have been integrated into hip protectors to provide both prevention and protection mechanisms (Hall et al. 2019; Hip Impact Protection 2024). It is not my intention to design or improve upon these existing systems as part of this PhD investigation, although this could potentially be part of further work after the completion of this project. However, one emerging area where fall detection systems are used – and is notable within the context of hip protectors – is inflatable technologies for protection.

Airbag hip protectors consist of a belt containing inertial sensors that can detect when someone is falling and deploy airbags automatically around the hips. The technology is also used in inflatable cycle helmets (Soal 2015), snow sports (e.g., Dainese 2023), motorcycling (e.g., Alpinestars 2023), and equestrian protective clothing (e.g., Point Two Airvests 2023). At the time of writing, these types of products are commercially available from three companies: Active Protective Technologies (Tango belt), Helite (Hip Guard)(see Figure 23), and S-Airbag (S-Airbag belt).

Photo of an airbag hip protector belt removed for copyright reasons. Copyright holder is Helite.

Figure 23. Helite. ca2023. Hip Guard airbag hip protector belt.

Two other companies report on their websites that they have airbag hip protector belts in development: Azimut Medical (Azimut Medical 2024) and Safeware (Safeware 2024). Most of these products are similar in style and all are worn over clothing. Dutch company, Wolk, take a different approach using airbag technology. Their Cloud airbag belt (see Figure 24) is designed to be worn under clothing, providing the advantage of discretion but also making it lighter and less bulky than traditional underwear hip protectors. Wolk's original approach, like their competitors, was a belt worn visibly over clothing that weighed 1kg. However, after the first 100 pre-ordered units were shipped, sales of the product were limited (Wolk 2024a). Customer feedback identified that users found it stigmatizing to wear, a critical issue missed through a technology centred approach to development. The later iteration of the product was slimmed down to fit under clothing and the weight halved (Wolk 2024a). The company have also recently launched an underwear version of the product, Wolk Shorts. It is not clear if wearing either product limits the clothing choices worn over it, i.e., if garments need to be loose fitting or elasticated to accommodate the inflated airbag.

Figure 24. Wolk. 2023. Cloud airbag hip protector worn between underwear and outer clothing.

No definitive trials have yet been conducted that examine the effectiveness of airbag hip protectors to mitigate hip fractures caused by falls (Tarbert et al. 2023). However, a retrospective pilot study using the Wolk Cloud indicates encouraging results, with a 45% decline in occurrence of hip and pelvic fractures across 11 residential care homes (Nemeth et al. 2022). The pilot study did not gather individual data and insight into acceptance and compliance was not recorded (Nemeth et al. 2022). However, customer feedback in response to the first iteration of the Wolk product demonstrates that the visual language of an airbag hip protector belt will be a motivating factor in terms of acceptance.

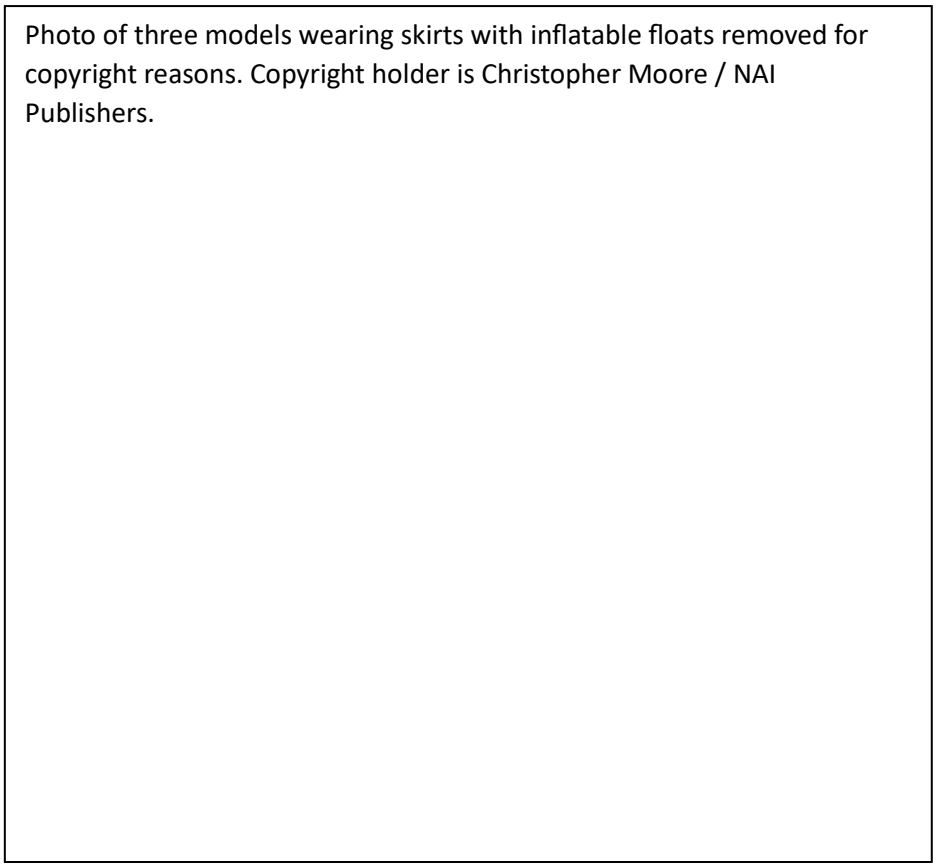


Figure 25: Chalayan. 2003. Inflatable floats explode from skirts in the Kinship Journeys collection.

Through challenging traditional modes of garment construction, the fashion designer Hussein Chalayan has built a career reimagining our relationship with clothing. In Kinship Journeys, Chalayan explored narratives of hope, sin, redemption, and salvation. Reference to the latter theme was reinforced at the end of the show, when the models' skirts (see Figure 25) exploded into inflatable lifejacket floats (Evans et al. 2005). This concept precedes airbag hip protectors by over a decade, simultaneously presenting a more sophisticated visual language than the airbag belts manufactured by companies like Helite.

More recently, designer Hanson Cheng has investigated ways of integrating airbag technology into other garments to protect people prone to injury from falls (Cheng 2020). The Pneu-tex jacket, inspired by athleisure and utilitarian fashion trends responds to the principle that protection should not compromise aesthetics. The jacket has inflatable panels to protect the wearer's hips, lower back, and arms. Cheng's approach is sensitive to a design language reflecting cultural norms and engages with the principles of empowerment discussed earlier (see 2.1.2), noting, "Products designed for fall protection should not embarrass the wearer. [They] should empower one to stay active and confident" (Cheng 2020). The length of the jacket could be an issue, however. The positioning of the

inflated panel over the hip seems a little high on the model to effectively cover the vulnerable greater trochanter.

The visual appearance of airbag hip protectors may not be the only barrier to their acceptance. The initial cost, and ongoing 'recharge' cost for these types of products presents a significantly higher financial outlay than traditional hip protectors. For example, the Wolk Cloud belt retails at €995 and replacement gas cartridges can cost as much as €65 (Wolk 2024b). Cianferotti et al. (2015) note that these types of devices could significantly improve comfort, therefore increasing compliance. However, the authors highlight the International Hip Protector Study Group (IHPSG) recommendation that economic analysis should be included in future clinical trials of hip protectors (Cameron et al. 2010). The complexity of these products, and related investment in R&D, is reflected in their high cost. But complexity can also impact on user experience and understanding of the product (Krippendorff 2006). For example, for a community-dwelling user, remembering to recharge the battery, or understanding how to replace the gas cartridge, could become triggers for disengagement, in addition to remembering to wear the airbag hip protector in the first place. User perceptions of living with this smart-technology is currently lacking in the literature (Quigley and Tarbert 2021) and is an important area for further investigation.

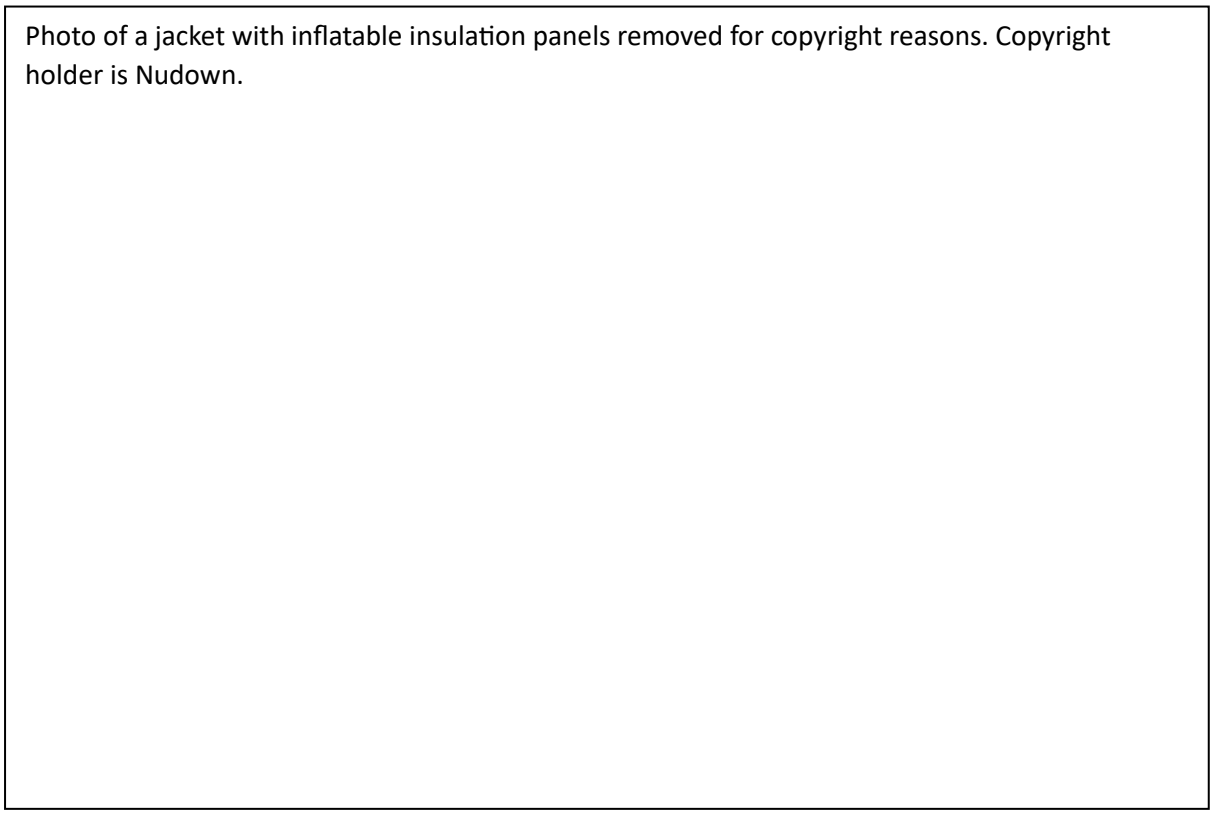


Figure 26: Nudown. 2018. Squaw Peak jacket with inflatable insulation.

Inflatable surfaces could offer a very lightweight means of protection from fall related injuries. It is therefore also worth considering opportunities for their implementation without the addition of complex and expensive smart technologies. For example, NuDown's inflatable jackets (see Figure 26), incorporating their patented NuTech technology (Hall et al. 2017; NuDown 2018), are designed to provide lightweight thermal insulation. By squeezing an in-pocket pump, air is forced into chambers surrounding the wearer's torso. The level of insulation increases as more air is pumped in, and can be reduced by letting the air back out (NuDown 2018). The same principle is applied to Nike's ISPA inflate jacket (Hypebeast 2024).

If the air chambers are designed in such a way that, when inflated, the jacket is still flexible enough to comfortably move in, then the concept could be adapted for impact protection instead of (or in addition to) thermal insulation. Protective areas on the jacket could potentially change shape to wrap around the body. Researchers in the field of 'soft robotics' are using pneumatic technologies to develop inflatable shape-changing materials. Ou et al. (2016) have investigated how these technologies can be applied to interaction design. Their aeroMorph project includes a workflow for designing, simulating, and fabricating transforming inflatables in a range of materials, including fabrics. Central to this technology are the geometric patterns in which the surfaces are heat sealed together to create interconnected inflatable chambers. In its simplest iteration, heat sealing in a diamond shape causes the surface to fold, like a hinge, as it is inflated (see Figure 27).

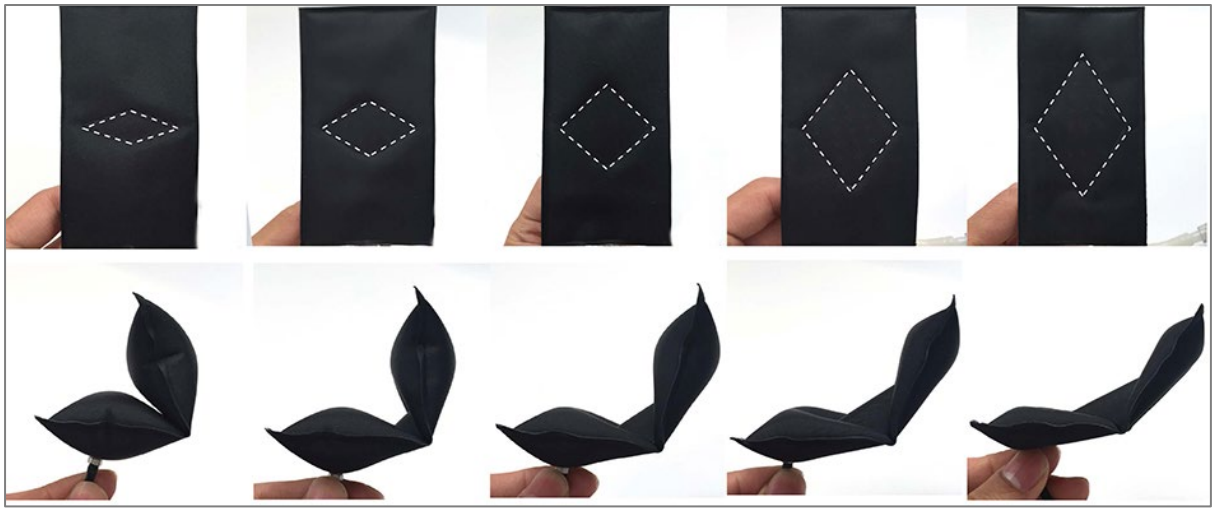


Figure 27: Ou et al. 2016. Samples demonstrating how the width/height aspect ratio of the diamond hinge determines the bending angle when inflated. (Image reproduced with permission whereby the copy is not made for profit or commercial advantage).

Adjusting the diamond geometry changes the folding properties of the hinge. The team used a custom heat-sealing head mounted onto a 3-axis CNC machine to precisely bond the surfaces in the programmed pattern. The work could be applied to the development of inflatable garments. Clothing that changes shape to fit closely around the body could be manufactured specifically for an individual using CNC technology. This approach brings together concepts relating to impact protection (airbags), but also overcomes usability issues of putting on or taking off tight fitting garments. An inflatable garment could be put on the body loose and then inflated to provide protection.

Inflatable surfaces could provide a lightweight solution to wearable impact protection. New airbag designs seek to provide more comfortable and discreet hip protection. However, this high-tech and expensive solution could overlook other critical user needs, potentially alienating some of the most vulnerable people at risk from falls. Acceptance of wearable airbags is an under-researched area, so further investigation is needed to understand perceptions of using these products. Passive inflatable garments, and shape-changing inflatable surfaces from the field of soft-robotics, provide new avenues to explore air inflated hip protection that is lower cost and less complex than airbag hip protector belts.

2.4 Discussion: Building a conceptual framework

The theoretical foundation for the study, presented at the beginning of this chapter, led to the review of literature and design precedents that followed, and will later inform the methods and analysis of the practice-based design research. This approach follows Grant and Osanloo's (2015) analogy, where a PhD research project is likened to the construction of a house. The house blueprint is a metaphor for the theoretical framework, providing the foundation for the research study, and the researcher's worldview from which all knowledge for the study emerges (Grant and Osanloo 2015). The theoretical framework is not the same as a conceptual framework (note also, I use the term 'theoretical foundation' to make the distinction clearer). The notional house blueprint representing the theoretical foundation describes the overall exterior elevation, i.e., the 'bigger picture'. The conceptual framework, developed from the theoretical foundation, seeks to understand how best to explore the research question, the specific direction the research will take, and the relationship between different variables in the study. This more granular understanding of the research project is represented as the house blueprint showing the floorplan, with interior spaces, lighting, services, etc.

(Grant and Osanloo 2015). To begin, the relationship between the theoretical foundation and the review of literature and current design practice is summarised below.

In the discussion on the culture of ageing (see 2.1.1), despite a rapidly ageing society, ageist attitudes remain highly pervasive (Centre for Ageing Better 2020). This is reflected in the way that products designed specifically for older people are often stigmatising (Coughlin 2017), or they are not considered at all, as seen in the sportswear industry (see 2.3.1). The risks of falls and fragility fractures for older people (especially those living with osteoporosis) are well understood (see 2.2.1). However, even internalised ageism impacts on an individual's perception of their own fall risk (see 2.2.3), and acceptance of hip protectors, especially outside the context of care homes, is low (Santesso et al. 2014). Cohen's (2006) four phases of adult development provide an established framework for considering the needs of potential hip protector users from mid to later life stages. By applying the framework to address the ageism associated with the design of hip protectors, a critical gerontological approach is enacted to not only understand the social construction of ageing but to change it (Phillipson and Walker 1987).

The notion of fashion as communication (see 2.1.2), engaging with clothing semiotics, reminds us that hip protectors are garments, subject to the same visceral judgement as other types of clothing. Many underwear hip protectors (see 2.2.2), however, exhibit high semanticity, expressing a visual language rooted in ageist notions of vulnerability and decline, and the idea of 'patienthood' as materialised ideology (Topo and Iltanen-Tahkavuori 2010). Understandably, dislike of appearance is a significant barrier to the acceptance of hip protectors (see 2.2.3). Barnard's (2007b) view of the way clothes are 'read' dismisses the idea of unilateral communication, but rather a cultural negotiation of their meanings. These interpreted meanings, however, are neither fixed nor absolute and are dependent on the context. On one hand, this signals the need for a variety of approaches to the visual language of hip protectors, that could reflect the socio-cultural aspirations of different types of wearers (i.e., people at risk of falls and fragility fractures are not a homogenous group). A one-size-fits-all approach will naturally be riddled with compromise. On the other hand, particular contexts, such as the domain of sportswear (see 2.3.1 and 2.3.2), could potentially position hip protectors as a positive symbol of active, healthy ageing. Not conveying vulnerability and dependency is critical, but it's also important that positive meanings are relevant to the context.

Finally, when considering a medical model versus social model (see 2.1.3) of design research, hip protectors sit firmly within literature from the fields of medicine, nursing, and gerontology. Engaging practice-based design research as consumer product design, rather than exclusively medical engineering, creates opportunities for a more holistic, inclusive design approach aligning with a

social model of development. The investigation into hip protection and gender (see 2.2.4), for example, demonstrates the need for a better understanding of both the physical and psychological requirements of women to inform hip protector design. In recognising that a broad range of effective energy absorbing materials exist (see 2.3.3) but barriers to the acceptance of hip protectors are persistent, greater emphasis should be placed on the design of the garment itself. Digital tools, such as 3D scanning and 3D printing (see 2.3.4), provide opportunities for human-centred and customisable approaches to hip protector garments. The emergence of inflatable hip protection (see 2.3.5) also presents new opportunities but is at risk of overlooking other critical user needs. Acceptance of wearable airbags is an under-researched area, so further investigation is needed to understand perceptions of using these products.

This review underpins the development of a conceptual framework to provide a lens through which the practice-based design research can be evaluated. Reflecting the theoretical foundation, the conceptual framework is built from three interrelated principles that embrace an inclusive design approach for hip protection garment development. They extend a design approach that prioritises the primary garment function of reducing hip fracture risk.

The three principles are illustrated in Figure 28 and expanded below:

- Hip protector design informed by both medical *and* social models of development, reflecting physical and psychological needs of users.
- Hip protector design that explores the cultural negotiation of their meanings, recognising they are neither fixed nor absolute and are context dependent.
- Hip protector design as critical gerontology, challenging ageist attitudes and developing new products that empower healthy ageing.

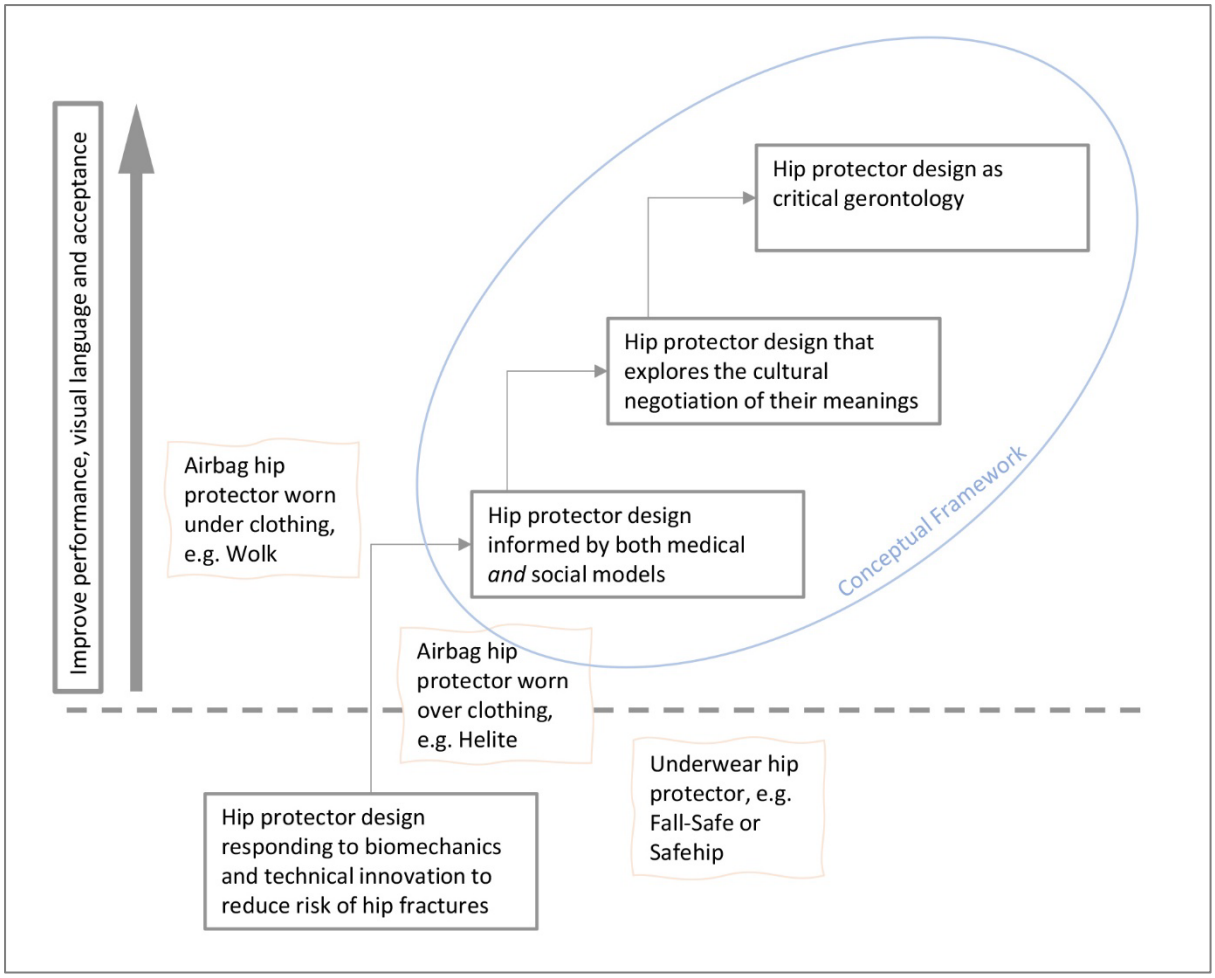


Figure 28: The conceptual framework as a lens to evaluate hip protector design in the context of current practice.

As Grant and Osanloo (2015) put it, the conceptual framework, "offers a logical structure of connected concepts that help provide a picture or visual display of how ideas in a study relate to one another within the theoretical framework". At the base level, an approach that prioritises technological innovation to reduce hip fractures inevitably problematises old age. Within the conceptual framework, central to each principle is an approach to tackle ageism or, indeed, any other ways people may be 'othered' due to their risk of falls or fragility fractures. The diagram (see Figure 28) presents a hierarchical structure to the conceptual framework, as 'stepping-stones' to challenge the function, meaning, and context of hip protector design. It suggests that as each level is engaged, greater improvement in the design of hip protector garments can be reached in terms of product performance, appropriateness of visual language, and overall acceptance. For example, the underwear hip protectors are found at the base level, responding to their reported barriers to acceptance. The potentially more comfortable and effective airbag hip protectors demonstrate improvements in design compared to underwear products. In particular, the Wolk airbag that is

hidden under clothing, reflects a social model of design by responding to customer feedback that a visible belt is stigmatising for users. The conceptual framework forms an important part of the overall research methodology which is discussed in the next chapter.

3 Methodology

This chapter begins with a methodological overview, stating my philosophical position, and providing the rationale for the approach taken. This is supported with reference to key theories that underpin the chosen methodology. A review of the research methods and data analysis follows, with a summary of approaches framed by the Design Council's Double Diamond model (Design Council 2024). This research project took place during the Covid-19 pandemic, so there is also a section describing the impact that social distancing rules had on the research methodologies and the subsequent changes to the approach that were necessary. Collaboration with industry partners has formed a critical part of the methodology relating to human-centred design research and concept prototyping. This is summarised in a later section before concluding the chapter with a review of research ethics.

3.1 Overview of practice-based methodological approach

This is a practice-based design research project involving a mixed methods approach. Both qualitative and quantitative methodologies have been used to discover new insights. The methodology engages with the three different types of research proposed in the seminal paper by Christopher Frayling: research *into* design, research *for* design, and research *through* design (Frayling 1994). Through more recent interpretations of Frayling's approach (Downton 2003; Vaughan 2017), the design practice is driven by the following modes of research:

- Research *into* design – to understand what has been done (historically and theoretically), i.e., insights established through the contextual review.
- Research *for* design – to use in application, i.e., building on the contextual review, insights through human-centred design research to understand the motivations, needs and desires of potential users to apply to the design of hip protectors.
- Research *through* design – to use design practice as a means of discovering something to be useful in articulating the intentions and outcomes of the research inquiry, i.e., insights through the iterative development of hip protector design concepts and practical experimentation with relevant materials and processes.

All types of research involve philosophical assumptions that naturally influence the planned methodology. Creswell (2003) suggests that when developing a plan, researchers make explicit their philosophical worldview to address how it has shaped their approach to research. This research project engages with the conceptual framework discussed in section 2.4, and aligns firmly with the pragmatic worldview derived from the work of Peirce, James, Mead and Dewey (Cherryholmes 1992). Pragmatism arises out of, "actions, situations, and consequences rather than antecedent conditions" (Creswell 2003: 10). In other words, research *for* and *through* design, not just research *into* design, to find solutions to problems. Researchers with a pragmatic world view emphasise the research problem and use all approaches available (mixed methods) to understand the problem (Creswell 2003).

The methodological approach presented here reflects Findeli's (1999) concept of project-grounded research. The project-grounded model is rooted in the pragmatic worldview where, "valid and trustworthy knowledge is best produced in experiential situations of inquiry" (Findeli 2016: 28). He draws from the work of John Dewey – the most influential educational theorist of the twentieth century (Kolb 1984) – to note that, "the task is to turn a merely empirical (project) experience into an experimental one" (Findeli 2016: 28). The project-grounded approach demands that design research produces knowledge that is useful for design practice at both a specific and generic level. Specifically, the research informs the development of designed artefacts, and more ambitiously, knowledge produced is also generalisable enough to be useful to design practice, whatever the specific brief may be (Findeli 2016).

The methods used to explore research *for* design and research *through* design are summarised later in this chapter. Overall, these two modes of research remain interdependent and equally represented throughout this practice-based enquiry and inclusive design approach. Many authors reinforce the value of working with stakeholders to solve design challenges (e.g. Clarkson et al. 2003; Mattelmäki 2006; Coleman et al. 2007; Conway 2008; Eikhaug 2010; Milton and Rodgers 2013; Lupton et al. 2014). The understanding of user needs informs the selection of – and designing with – materials and processes that reflect these needs. Equally, the iterative design development and experimentation with materials and manufacturing processes informs the physicality of proposed design details. Through sampling and test pieces, this also produces a range of artefacts to inspire and direct future design proposals. The research *through* design has generated knowledge that specifically informs the design of hip protector garments. By generating practice in response to the

conceptual framework, a set of principles are tested to produce knowledge relating to inclusive design approaches that are useful to design practice more broadly.

The situated nature of this practice-based enquiry, as Vaughan puts it, “ensures that research undertaken will produce knowledge that both deepens understanding and provides practical applications for practice" (Vaughan 2017: 10). She argues that research *for* design demands comprehensive social research, but it is the immediacy of action this type of research delivers that differentiates it from, “more objective, understanding-focused social research, which may or may not have extrapolated recommendations in its conclusions" (Vaughan 2017: 31). This approach is embraced through the qualitative research methods that engage with potential hip protector users. Findeli argues that the responsibility for this aspect of the research is on the *design researcher*, whose task it is, “to uncover the specific anthropological issue at stake and to elaborate the proper research inquiry” (Findeli 2016: 30). He continues that it is the task of the *designer* to deliver an adequate proposal to the stakeholders. In this practice-based enquiry, I will embrace both these approaches as a ‘designer-practitioner-researcher’ (Vaughan 2017).

Subasi and Malmborg's (2013) model for “ageing as design culture” is a useful framework for designer-practitioner-researcher engagement in the domain hip protector development. Their notion of ageing as design culture, “avoids categorising people by age or deficits, but considers possible constraints of environments, or changes in the life course, in the design process” (Subasi and Malmborg 2013). This aligns directly with the principle of hip protector design as critical gerontology addressed in the conceptual framework. Their model emphasises four key themes for collaborative design practice with older people, which I have expanded with reference to my research below:

- Definition of ‘notion of elderly’ – avoiding a generalisation of ‘the elderly’ as a homogeneous group and defining heterogeneity in ‘ageing well’. Reflected in Cohen's (2006) four phases of adult development.
- Situated elderliness – the situational aspects that can affect the perception of the self as ‘elderly’. This is the context of falls, hip fractures, and resistance to hip protectors, namely “the specific anthropological issue at stake” (Findeli 2016).
- Communities of practices – working with older people in their local environments and daily settings. Relates to human-centred design research, especially with ‘active agers’, attending exercise and balance classes (see 3.5).

- Role of the designer – the practice of design and design research paradigms. The research *into* design, research *for* design, and research *through* design.

In response to the final point, the process of interpreting research data and applying it to the creative development of design concepts services its own knowledge creating purposes. This aspect of research *through* design reflects Attiwill's assertion that with a practice-based approach, "the idea of the scientific paradigm that confirms the value of research as one of repetition by others to achieve the same outcome is neither a useful measure nor orientation in attending to subjectivities and production of the 'new'" (Attiwill 2016: 43). However, it is important to recognise in this research project, that empirical methods have yielded a knowledge base to frame the research inquiry, upon which the creative investigation is built. Herein lies the inherently paradoxical nature of design research. McDaniel Johnson (2003) argues that this type of research is both empirical and imaginative because often the 'typical' user that researchers need to understand aren't always able to articulate their needs. "Design researchers must go beyond what they can find: to see more than is visible, and to learn more than can be heard. Accordingly, design research is an act of imagination, just as much as design itself." (McDaniel Johnson 2003: 39).

This aspect of the research reflects the notion of 'practice as research' (PaR), described by Nelson as involving a PhD project, "in which practice is a key method of inquiry and where, in respect of the arts, a practice is submitted as substantial evidence of a research inquiry" (Nelson 2013: 9). Nelson's approach challenges the strong academic research tradition of 'the scientific method', however, focuses primarily on visual arts and performance. His preference for PaR to be underpinned by a 'research inquiry' rather than a 'research question' resonates with this project. His challenge to the scientific method, that "questions imply answers", is reflected in the more specific context of design thinking by Nigel Cross who notes that, "the creative designer interprets the design brief not as a specification for a solution, but as a starting point for a journey of exploration" (Cross 2018: 8). In this respect, the research question posed at the beginning of this thesis invites an exploratory process through which multiple design solutions – or 'answers' – could emerge.

This type of research through exploration – or research *through* design – aligns with the principles of 'Action Research', a model originally developed by the social scientist Kurt Lewin in the 1940s (see Figure 29). It is a cyclical process, consisting of four stages, that begins with real-world actions (concrete experience), followed by observation and reflection of the experience. The findings then inform new ideas that lead to an improved outcome which become the focus of new actions and

experiences (Kolb 1984). The two key aspects of the model are what Kolb describes as the, "*here-and-now concrete experience* to validate and test abstract concepts" (Kolb 1984: 21), and the *feedback processes* which provides the basis for, "goal-directed action and evaluation of the consequences of that action" (Kolb 1984: 22). Lewin's model, along with the work of Dewey and Piaget, were the foundation for Kolb's own model for experiential learning determining that, "learning is the process whereby knowledge is created through the transformation of experience" (Kolb 1984: 38).

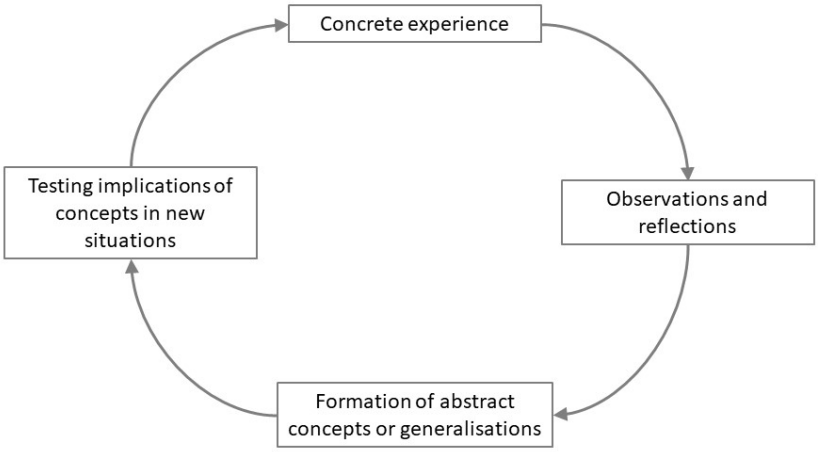


Figure 29: The Lewinian model for Action Research. Reproduced from Kolb (1984).

Throughout this research project, the Action Research model is applied to the iterative development of hip protector design concepts and prototypes. In the broadest sense, this is demonstrated in Figure 30.

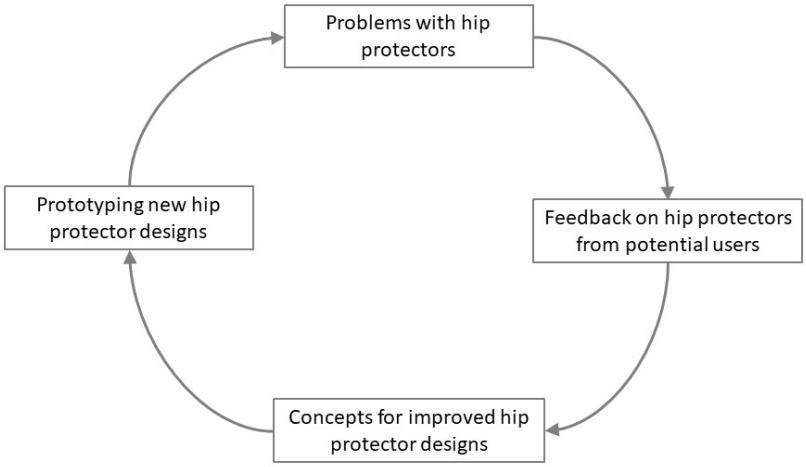


Figure 30: The Lewinian model for Action Research applied to this practice-based research project. Adapted from Kolb (1984).

Concrete experience of the problems with existing hip protector garments is established through physical examples and discussion in the literature. Observation and reflection relating to the perception of these garments is gained through talking to experts and potential users. Concepts for new hip protector garments are developed that overcome the perceived disadvantages. Finally, prototypes are developed to test these new concepts. The prototypes then become the next focus of concrete experience and the cycle begins again. Although Action Research can be applied to any practice-based inquiry, the model very clearly aligns with the iterative process of design research.

3.2 Research methods

This research project uses the Design Council's double-diamond methodology (Design Council 2024) as an established structure to frame the research methods. The diagram embraces both the divergent and convergent thinking that captures the nature of the investigation during four (again) distinct phases and informs the appropriate methods of research (see Figure 31).

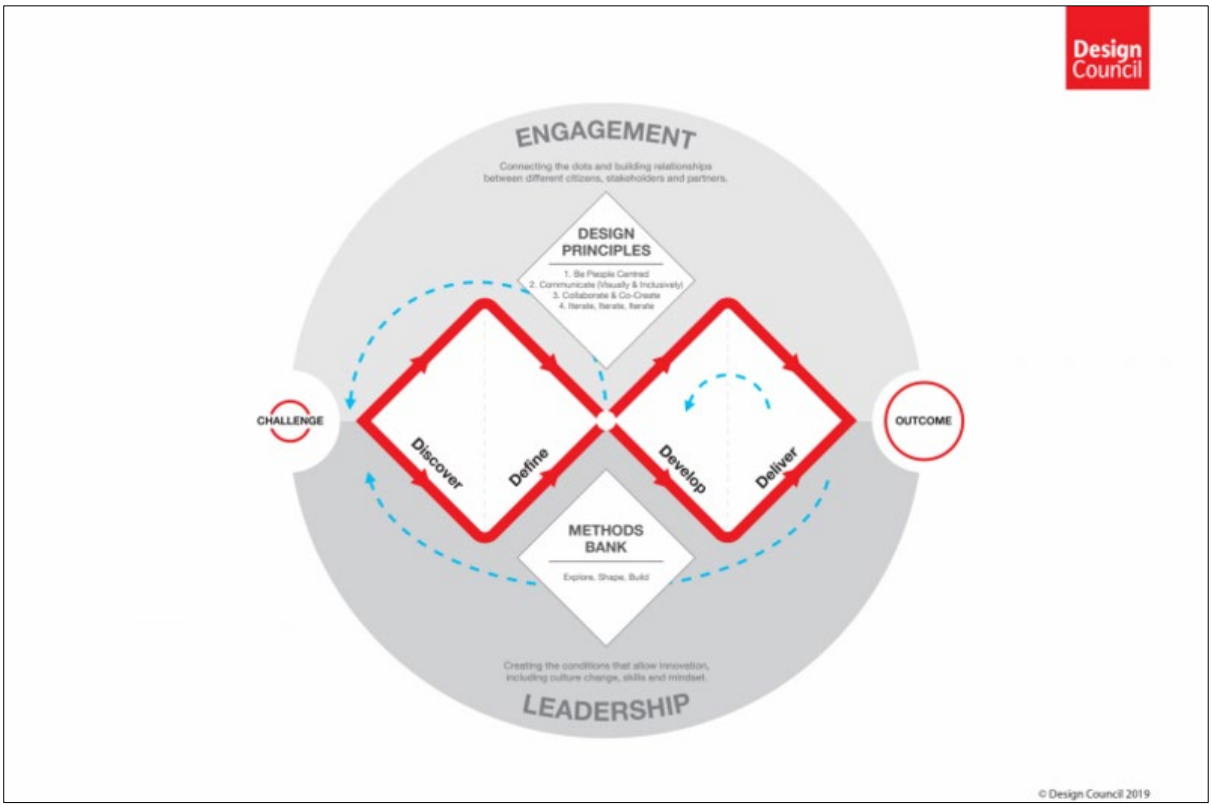


Figure 31: Design Council. 2019. Double Diamond Model.

- Discover – involves gaining insight into the problem, including speaking to people affected by the issue.
- Define – the earlier insights are used to clearly frame the challenge and determine the project direction.
- Develop – different answers to the problem are explored engaging with potential users.
- Deliver – the opportunity to establish what works, and importantly what does not work, through prototyping and testing.

(Design Council 2024)

The phases reflect the cyclical iterations of the Action Research model. In 2019, the Design Council evolved the model in response to criticism that it was too linear. This included adding arrows that indicate: previously unrecognised problems can lead back to the beginning; making and testing early on can be part of the discovery; and 'final' designs are always subject to ongoing feedback and improvement (Design Council 2024).

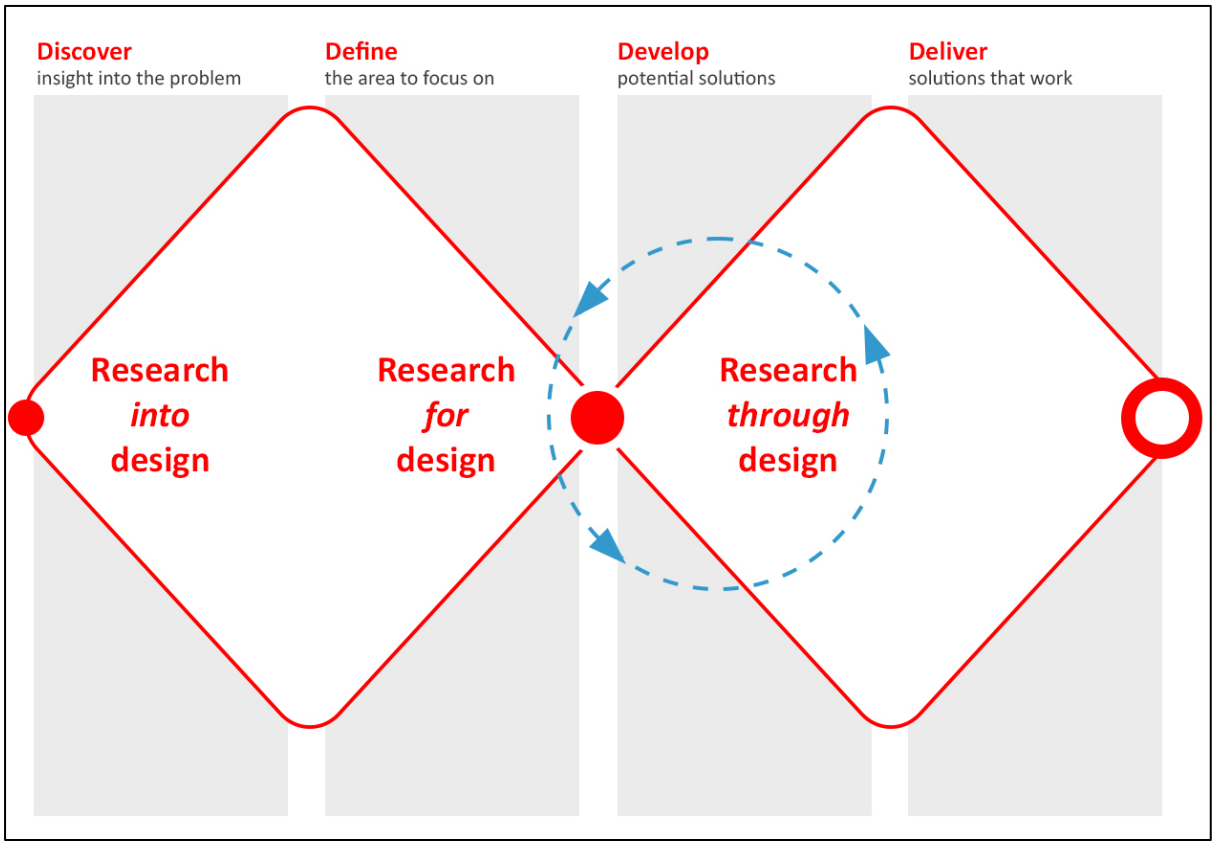


Figure 32: The modes of design research aligned to the Design Council's double-diamond methodology

Similarly, for this practice-based project, the model has been used as an overarching guide to the design research rather than a rigid timetable for praxis. Figure 32 shows how the phases of the double-diamond also reflect the three modes of research *into* design, research *for* design, and research *through* design.. This underpins the way the framework positions research methods at different stages of the project providing a visual structure to the methodology (see Figure 33).

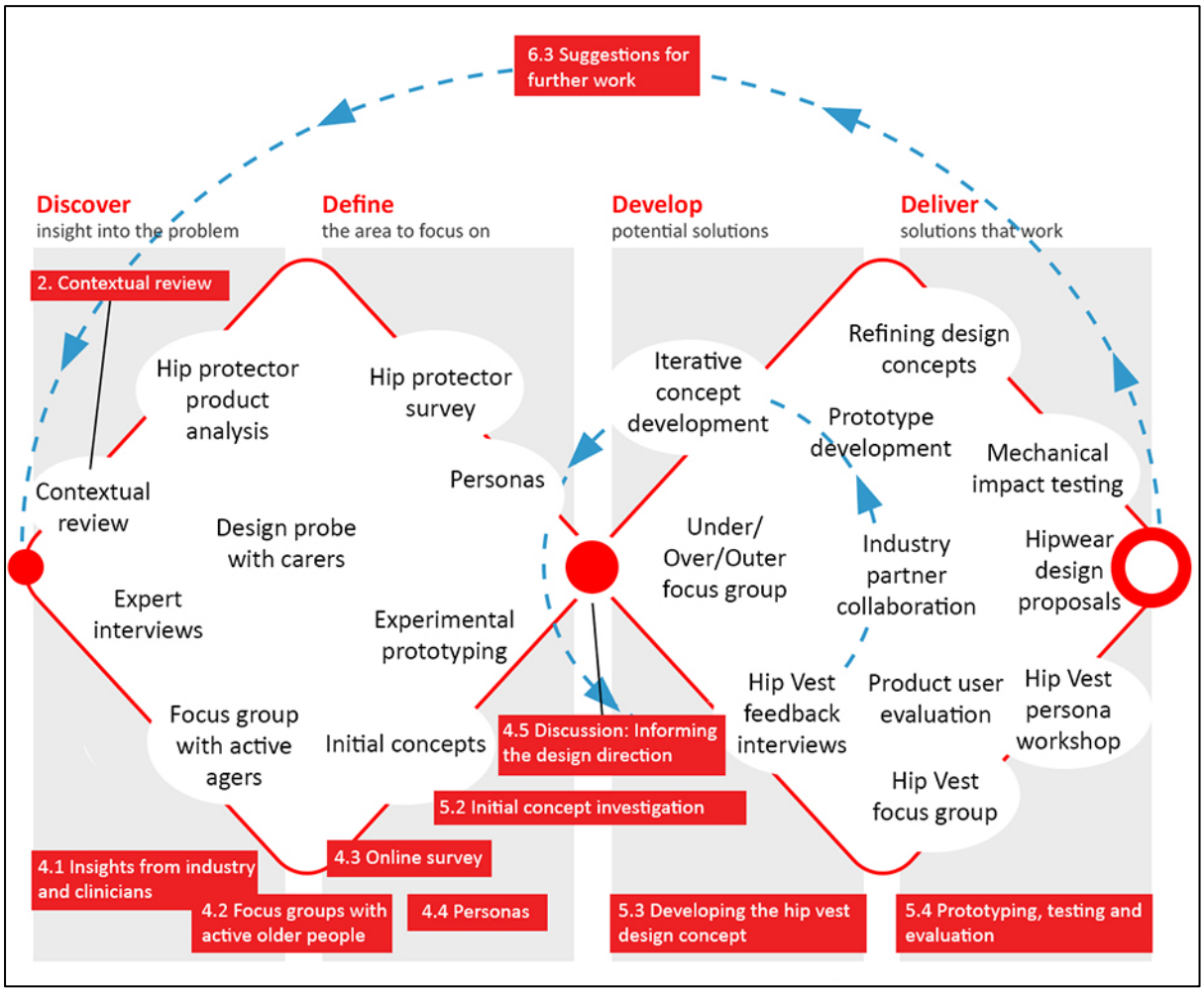


Figure 33: Summary of research methods and thesis chapters aligned to the Design Council's double-diamond methodology.

The iterative nature of the design process is represented through the circular arrow through the develop and deliver phases. Like the Design Council's original model, these cycles occur elsewhere, for example, in the way that 'experimental prototyping' defines the project direction but is part of the discovery. Reflecting on the principles of project-grounded research, knowledge that is specific to the design brief emerges across the four phases. Knowledge that is more general to design practice is explored through the conceptual framework (established in chapter 2), a lens through which the

design practice is evaluated and a model that could potentially be applied more broadly to designing products for older people. The diagram also indicates the thesis chapters where the practice-based design research is discussed and reflects the opportunity for ongoing design development through suggestions for further work.

The secondary research informing the contextual review was established through the 'discover' phase. This primarily consisted of research *into* design to understand the problem of falls and hip fractures and existing types of protective clothing and technologies. The theoretical foundation for the study was also established here, leading to expert interviews to gain further insight into the problem. The contextual review lay the foundation for the direction of the design research, culminating in establishing the conceptual framework.

The 'define' phase also included gathering the views of potential hip protector users and healthcare professionals through interviews, focus groups, and an online survey. This research *for* design helped to understand what is perceived as acceptable, in terms of aesthetics and function, and expectations of product cost. This work coincided with an initial investigation into materials and fabrication methods, informed by early design concepts, as the beginning of the research *through* design process.

The 'develop' phase built on the initial concept development and saw the generation of physical prototypes that were iteratively tested and evaluated. The practice included prototyping I carried out in Falmouth University's workshops, and prototypes I designed but were manufactured by the industry partner, DM Orthotics. A focus group with active agers was developed as part of this process in response to hypothetical concepts, and further feedback on a more refined design proposal was gained later through a series of telephone interviews.

The 'deliver' phase represented the final stages of the design research and proposal for 'hipwear' garments. Empirical research into the force attenuation properties of protective materials was established through mechanical impact testing. Physical testing for comfort and usability was conducted by a group of participants at low risk of falls or fragility fractures. This stage also offered a final period of reflection to evaluate the relationship between the design outcomes and the conceptual framework.

A more detailed explanation of how the research methods have informed the development of the research will be discussed in the relevant phases across chapter 4.

3.3 Data Analysis

A range of approaches to analysing and interpreting data have been adopted throughout the research. These are relevant to the project-grounded, mixed-methods, *mostly* qualitative nature of this investigation (a quantitative method was adopted for empirical research through mechanical impact testing, for example). Creswell (1997) suggests that no consensus exists for analysing qualitative data but presents the general data analysis strategies advocated by three authors of qualitative research methods (Bogdan and Biklen 1992; Huberman and Miles 1994; Wolcott 1994) (See Table 4).

There were seven key points during the project when qualitative data analysis occurred:

- Insights from industry and clinicians (see 4.1)
- Focus groups with active older people (see 4.2)
- Online survey: Perceptions of fall risk and attitudes towards hip protectors (see 4.3)
- Personas (see 4.4)
- Under/Over/Outer focus group (see 5.2.3)
- Hip vest feedback interviews (see 5.3.2)
- Product user evaluation (see 5.4.2)

In general, note taking and noting patterns and themes, were used to deal with the data relating to insights from industry and clinicians. This comprised of expert interviews and a design probe exercise where the data was also contextualised in relation to the conceptual framework derived from the literature.

Coding, counting the frequency of codes, and reducing information through clustering, were applied to the data relating to insights form potential hip protector users. This included a focus group with active older people, but the most significant volume of data came from the online survey titled 'Perceptions of fall risk and attitudes towards hip protectors'. Data was visualised using tables and graphs, and identified patterns and themes led to the development of personas, imaginary characters that represent different user archetypes based on real people (Dam and Siang 2024). The personas helped to focus the design practice on the specific needs and desires of users and provide a useful tool to evaluate design concepts. Data analysis at this stage also included 'building a logical chain of evidence' as the findings were assimilated into a product design specification.

Table 4: General data analysis strategies by authors of qualitative research methods. Reproduced from Creswell (1997).

Analytic Strategy	**Bogdan and Biklen (1992)**	**Huberman and Miles (1994)**	**Wolcott (1994)**
Sketching ideas	Jot down ideas in margins or fieldnotes	Write margin notes in fieldnotes	Highlight certain information in description
Taking notes	Write memos, write observer's comments	Write reflective passages in notes	
Summarise field notes		Draft a summary sheet on fieldnotes	
Getting feedback on ideas	Try out themes on subjects		
Working with words	Play with metaphors, analogies, concepts	Make metaphors	
Display data	Develop diagrams, continua, tables, matrices, and graphs	Make contrasts and comparisons	Display findings in tables, charts, diagrams, and figures; compare cases; compare with a standard
Identify codes	Develop coding categories	Write codes, memos	
Reduce information	Sort material into categories	Note patterns and themes	Identify patterned regularities
Count frequency of codes		Count frequency of codes	
Relating categories		Factoring, noting relations among variables, building a logical chain of evidence	
Use systematic procedures of tradition of inquiry			Follow fieldwork procedures in ethnography
Relate to analytic framework in literature			Contextualise in framework from literature
Redesign study			Propose a redesign of the study

Getting feedback on ideas was a key analytical strategy used across the Under/Over/Outer focus group, the hip vest feedback interviews, and the prototype user evaluation. Coding, counting the frequency of codes, and reducing information through clustering, were also strategies employed to systematically evaluate and ratify the design decisions made.

Finally, during the 'deliver' phase of the design research project, a drop test tower was used to compare the peak impact forces and percentage impact attenuation of a range of hip protector pad prototypes and commercially available hip protectors (see 5.4.1). This quantitative research data was critical to establish the suitability of impact absorbing materials to reduce the risk of hip fractures in the event of a fall.

3.4 Impact of Covid-19 on the research methodology

This research project was in the 'define' phase when the Covid-19 global pandemic began. In the context of researching older people at risk of falls, there were significant moral and ethical challenges connecting to an audience who were particularly vulnerable to the virus. The need to adapt research methods quickly, coupled with the pressure of lockdown life, impacted on the time and 'thinking space' needed for the project. I published a paper exploring the way design-led research was adapted in response to the extreme situation caused by the pandemic (Andrews 2023). Human-centred design research was able to continue without direct access to people at risk of falls using personas developed from online survey data. These methods are discussed in section 4.4, but a summary of the impact of Covid-19 on the research methodology is presented here:

In March 2020, when the first UK lockdown occurred, the research was at a critical stage of recruiting participants to take part in focus groups. These would involve older participants discussing hip protectors face-to-face and handling physical samples and prototypes. Around 20 participants across community and care home environments were to be recruited, engaging with project partners iCareiMove and Cornwall Care respectively. The constraints enforced through social distancing rules made it impossible to continue the research this way. In particular, it was unknown how long restrictions on care home visitors would be in place and if it would ever be possible to engage with this audience within the remaining timeframe of the PhD. The research therefore pivoted to 'active-agers' and people generally more susceptible to fragility fractures. This led to a new avenue of investigation, understanding the opportunities for hip protection including younger audiences, paving the way to breakdown ageist stereotypes of hip protectors and the development of more inclusive designed products.

As in-person interactions moved to online platforms such as Zoom and Microsoft Teams, it was a natural response for research with participants to follow suit. However, the purpose of the original focus groups was to engage with the materiality of product development, with opportunities for

participants to handle samples and physical prototypes. There are precedents for running online human-centred design research (e.g. frog 2020; Goodpatch 2020) but the lack of ability for feedback on materials would have made these far less worthwhile. The idea of posting samples to participants in advance of an online focus group was considered, but the cost, and concerns about coronavirus surface contamination made this unfeasible. The uncertainty of when things would return to 'normal' was the driver to develop an online survey as a rational way of maintaining primary research activity during this challenging period.

The online survey, targeted at members of the Royal Osteoporosis Society (ROS), provided key insights into attitudes towards existing hip protectors and data relating to lifestyles and the contexts of hip protector use. This directly informed the development of new types of hip protection but also helped to develop the design personas reflecting a range of potential users. These methods will be discussed in more detail later, but both extended opportunities for the research to develop in different, yet still meaningful ways, despite the pandemic. I am very grateful to the ROS for their cooperation and providing access to their membership.

Access to prototyping facilities were also limited at this time, so there was uncertainty about ongoing design practice, the exploration of materials and processes, and development of prototypes. Fortunately, limited access to Falmouth University workshops was available in the months between lockdowns, and opportunities for this kind of research became viable again later as social distancing rules relaxed. However, the extent to which design practice could operate was significantly impacted by the pandemic. Prototyping support with project partner, DM Orthotics, was disrupted with very little engagement between Dec 2019 (the last in-person meeting before the pandemic) and May 2021. As a result of this, the research *through* design turned to digital tools to visualise and articulate design details. In particular, I used the time during lockdowns to advance my skills using CLO 3D fashion design software (CLO 2024). This allowed for a digital exploration of design concepts, offering a good understanding of fabric properties and garment manufacturing detailing in the absence of physical prototypes. The outputs using this software provided a strong basis for prototyping actual hip protector garments when social distancing rules were eased.

3.5 Collaboration with industry partners

Two industry partners, DM Orthotics and Cornwall Care, were negotiated and agreed by the 3D3 Centre for Doctoral Training as a requirement for the PhD scholarship to be supported by the

National Productivity Investment Fund (NPIF). The role of the partners was to support empirical and practice-based research as part of the investigation. DM Orthotics is a world leading provider of medical rehabilitation and sports performance products, based in Redruth, Cornwall (Foxcroft 2019). At the beginning of the research, Cornwall Care, were the largest care provider in Cornwall, with 16 care homes offering residential, nursing and dementia care (Cornwall Council 2017). They were acquired by care provider, Sanctuary, in 2022 (Sanctuary 2022). One further industry partner, iCareiMove, established later, are a Cornish fitness and wellbeing company specialising in keeping older people healthy, active, and confident (iCareiMove 2024). Their expertise related to healthy ageing has helped to support the research, particularly by providing access to their clients as active older research participants.

DM Orthotics have supported the research by contributing to the development of prototypes via their garment factory. In this respect they have acted as a manufacturing contractor as is typical in design practice. Throughout the collaboration, I have provided them with test pieces, mock-ups, CAD visuals and drawings, that have informed the production of prototype garments. This has been an important part of the evaluation of design concepts throughout the Action Research. This 'payment in kind' of staff time and resources secures DM Orthotics' position as an on-going collaborator, to potentially commercialise ideas that emerge from the research at the end of the PhD project. A mutual Non-Disclosure Agreement (NDA) was signed between the company and Falmouth University to reflect this intention. From the 'define' phase, regular meetings took place with key personnel at DM Orthotics, including Anna Short, Pattern Designer/Developer, and Martin Matthews, Managing Director.

Cornwall Care provided access to their care homes and staff to understand the context of falls and hip protection in a care environment. During the early stages of the project, I visited three care homes: Mountford House and Redannick House, both in Truro, and Trevern, in Falmouth. Initial meetings took place with the care home managers to discuss the use of hip protectors and the opportunities for engaging staff and residents in research activities. A design probe research method was developed for staff at Mountford House and an expert interview was conducted with Cornwall Care's Senior Physiotherapist, Pat O'Brien (both methods are discussed later in 4.1.1 and 4.1.2).

Research activity with Cornwall Care unfortunately ceased at the beginning of the pandemic. At that time, opportunities to research potential hip protector users were also already established through iCareiMove and some of that activity was able to continue remotely. The focus of the project also shifted to the wider community, not only older people living in care homes. In this respect, the

relationship with Cornwall Care was not restored after restrictions on access to care homes started to lift.

An NDA was also signed by the iCareiMove directors, Helen Tite and Pat Taylor. This has allowed discussion about design concepts to occur as they have developed and provided informal feedback and guidance. Interaction with iCareiMove mostly occurred during visits to Carnon Downs village hall where they run the exercise classes. A pre-participation meeting, focus groups, and later feedback sessions took place there with their clients and will be discussed chapter 4.

Finally, an informal interview was conducted with Tony Ka Yui Wang, Managing Director at Bodywear Lab, to help inform the contextual review (see 2.3.2). Bodywear Lab also signed an NDA to support these discussions.

3.6 Research Ethics

Ethical approval was granted by the UAL Research Ethics Sub-Committee (RESC) in July 2018. An earlier research ethics application had been rejected on the basis that older participants were to be asked to trial hip protector prototypes to evaluate their look and feel. The UAL RESC decided that the risks associated with this would be too difficult to manage and presented too great an ethical challenge. The application was amended so that older adults at higher risk of falls could be included in the research but only to evaluate the appearance of hip protector garments and prototypes. This would include handling physical samples but not actually wearing the garments.

Participant information forms were provided to everyone taking part in a formal interview or focus group. Participants were also asked to sign consent forms agreeing to their involvement in the research (examples of participant information sheets and consent forms are included in Appendix E). Participants were aware that they could leave the study at any time. Survey respondents were provided information as to how their data would be used and provided consent by completing the survey. Similarly, Cornwall Care staff consented to their feedback being used in the research based on taking part in the design probe exercise. A risk assessment was carried out for off-site research activity to mitigate against the risks as part of the original research ethics application.

At the beginning of the Covid 19 pandemic, interactions with research participants could not continue face-to-face. However, changes to the research methods did not impact significantly on the ethics review. An online survey and interviews had already been agreed and signed off through the ethics review process, although participant information and consent forms were updated to reflect

these alternative interaction methods and provide transparency on the gathering and storing of data this way. A research ethics addendum to the original application was agreed by the UAL RESC in October 2020.

Although I was not permitted to ask older people at risk of falls to wear and evaluate prototype hip protector garments, I was able to trial prototypes myself to gauge their overall comfort and wearability. This was an important part of the process that supported the iterative development of design concepts but had clear limitations in terms of addressing the needs of the target audience, particularly women. To get a broader perspective on comfort and wearability, younger participants from Falmouth University's student population were recruited to trial a concept where the protective pads were integrated into the lower portion of a vest garment. Before this study took place, a new research ethics application was submitted to Falmouth University's Research and Innovation Ethics Committee (RIEC) which was accepted in Nov 2022. As with the initial project introduction to iCareiMove participants, I ran a pre-participation meeting to discuss the scope of the project and talk through the participant information form. Similarly, the student participants trialling the prototypes signed a consent form before taking part in the research.

A risk assessment was carried out in advance of the prototype trials and measures put in place to mitigate against risks. Testing of the efficacy of impact protection with users was not part of this research, and prototype garments under review contained 'dummy' hip pads to represent material thickness and feel. This provided minimal impact protection, which participants were made aware of through the participant information form and verbal briefing, in advance of the activity.

3.7 Discussion: Evaluation of methodological approach

The methodological approach reflects the transdisciplinary nature of this research project, engaging with the topics of critical gerontology, technological innovation, and clothing semiotics. Whilst my experience as a product designer is central to the practice, the research also engages with the fields of biomechanical engineering and fashion and textiles design. These wider domains are embraced through research *into* design, research *for* design, and – especially related to design practice – research *through* design. The breadth of this practice-based design research necessitates a mixed methods approach.

Building on the contextual review, the emphasis on qualitative research, anchored in human-centred design research methods, is fundamental to assimilating knowledge from relevant practitioners, and

understanding perspectives from potential hip protector users. A mixed methods approach allows themes and design opportunities to be identified through repeated patterns that emerge through the qualitative data. This triangulation of sources helps to ensure rigour in the interpretation of data. The findings will be consolidated in a list of design criteria currently overlooked in existing hip protector garments, to inform the design practice.

The research question seeks to understand how hip protecters can reflect the socio-cultural and lifestyle aspirations of the people who would benefit the most from wearing them. It is important to recognise that people at the highest risk of hip fractures are not a homogenous group. Indeed, this has been a failing of many products designed for older adults. The research methods adopted allow for a wide range of views to be gathered, including through focus groups with 'active agers', and the online survey, across mid-life to older age of people living with osteoporosis. The diversity of potential users means that there is no 'one-size-fits-all' approach to the design outcome. The approach to the design practice looks to satisfy the needs of the largest proportion of people, especially women who are most at risk of hip fracture but are underrepresented in the current design of hip protectors. This reflects the exploratory process through which multiple design solutions could emerge.

Action Research is an established, reliable methodology that clearly aligns with the principle of iterative design development. The model engages directly with empirical research, gathering ideas or feedback to improve hip protector concepts, or practice-based experimentation, such as the mechanical impact testing of energy absorbing materials. Action Research exists throughout the research *through* design, but the model is used implicitly as design ideas are conceptualised, evaluated, and then further developed.

Finally, the methodology has been developed to engage directly with the three interrelated principles of the conceptual framework. The conceptual framework not only underpins the direction the research will take and the relationship between different variables, but also provides a focus for the project-grounded approach. By testing the conceptual framework as a vehicle for innovation in hip protector design, the potential for it to be more broadly applicable to design for healthy ageing can be evaluated.

The research methods continuing to 'discover' insights into the design opportunity, and 'define' the direction for design development, are explored in the next chapter.

4 Hipwear: Discover and define phases

In this chapter, I present the design research engaging with the first two phases of the Design Council's Double Diamond: discover and define. The investigation, using a combination of qualitative and quantitative methods, is discussed through the sections below, exploring human-centred methods to understand the issues and define the design direction. An analysis of these findings and consolidation of criteria to inform the design approach is then discussed at the end of the chapter in section 4.5.

Primary research through the 'discover' phase is largely centred in Cornwall, UK. As I am based in Cornwall, this has mostly been due to convenience. However, between 2011 and 2021 the Cornish population of 65 to 74 year olds rose by about 16,000 (an increase of 25.9%), while the number of 35 to 49 year olds fell by about 8400 (8% decrease) (Office for National Statistics 2022). Indeed, Cornwall has a higher average age (47 years) than England as a whole (40 years) (Office for National Statistics 2022) so is well positioned for research related to older age.

4.1 Insights from industry and clinicians

I conducted expert interviews with individuals whose professional experience would help understand the design problem and shape the direction of the project. In response to the conceptual framework and considering hip protector design informed by both medical *and* social models of development, interviews were conducted with a gerontological physiotherapist, an occupational therapist, and a fashion designer. These three professions provided insight into the design and use of hip protectors across a spectrum of expertise, from clinical to design intervention. Although it was helpful to understand the role occupational therapists have in falls prevention, the interview is not discussed in this thesis as the interviewee had no direct experience of advising clients to use hip protectors. Further insight was gained through a 'design probe' exercise with staff working at Mountford House care home, in Truro. Access to the care home was granted by industry partner, Cornwall Care, to investigate issues relating to hip protector use in a residential care setting.

Although I placed greater emphasis on gathering the views of clinicians, the interview with the fashion designer, Fanny Karst, was particularly useful as she specialises in designing garments for older women. Karst is a French designer, based in New York, who has built her career designing

clothes for older women. Karst's inclusive approach, recognising older women's needs, is noted by Lacoste-Kapstein (2011), which motivated me to seek an interview with her.

The issues relating to falls, the nature of hip fractures, and existing hip protectors were explored extensively through the literature presented in medical journals. It therefore felt less critical to interview, for example, an orthopaedic surgeon whose concern is the specific treatment of a fractured hip. This decision was reinforced by the desire to shift the emphasis of hip protection away from being a medical intervention to a desirable lifestyle product.

4.1.1 Interview with a gerontological physiotherapist

The interview with gerontological physiotherapist, Pat O'Brien, took place at the headquarters of Cornwall Care, where O'Brien was a senior physiotherapist.

4.1.1.1 Methodology

I adopted an unstructured interview approach where the key topics of ageing, falls, and the design of current hip protectors, particularly within the context of care homes, emerged through the discussion. Milton and Rodgers (2013) note that unstructured interviews allow respondents to direct the discussion towards issues that they consider the most important, rather than working from predetermined questions. This was an appropriate approach at this stage of the project as it was the first meeting with Cornwall Care and the beginning of the process to understand the contexts of hip protection in care homes. The interview was not recorded but notes were taken throughout the meeting and written up to provide a formal record of the conversation, later validated by O'Brien.

I showed the Fall Safe underwear hip protector and the Protex HiP padded belt hip protector (both described in section 2.2.2) to O'Brien to act as interview prompts. Overall, the interview provided critical insights into prevention and protection from falls in care homes. The research question was explored, focusing on which people are most at risk of hip fracture, how the design of existing hip protectors can be developed or challenged, and what other performance requirements exist beyond reducing hip fracture risk. This established some key themes to further inform a product design specification, and to explore further through other research methods.

4.1.1.2 Interview analysis and discussion

As a physiotherapist, O'Brien's role within a care home provider is quite unusual and she noted that physiotherapy is most often outsourced. However, Cornwall Care benefit from her working in-house to provide focused support and strategies to improve care, particularly relating to falls and fall prevention. She has done much research herself within this domain, including her own study of residents in Cornwall Care homes to track fall occurrences and identify the groups most at risk.

Through experience running 'falls, balance, and exercise classes' for older people, she described her clients in terms of a spectrum, from initial increased fall risk through to very frail and high fall risk, typically including care home residents. The scope of individuals at different life stages and a variety of different needs reinforces the wide range of contexts where hip protectors could be beneficial. This supports the value of using personas (explored later in section 4.4) to reflect the diversity of different potential users.

She described the crisis in the care industry, driven by a lack of funding and resources, that has impacted on the availability of support for care home residents at the highest risk of falling. Even before the pandemic this bleak situation was well reported in the media (Owen 2015; Brodbeck and Dyson 2017; Ruddick 2017; Davies 2019). She also noted how there is no NHS funding for hip protectors and the cost must be met by the client or their families. The affordability of hip protectors is therefore of significant concern in terms of accessibility and acceptance.

O'Brien is cautious to advise the use of hip protectors to all her clients, even if they are at risk of falls. In her unpublished study she found that 83% of the fallers in Cornwall Care homes had dementia. This is echoed in the literature on fall risk and dementia (e.g. Fernando et al. 2017) with a double to threefold risk of falls compared to people without dementia (Härlein et al. 2009). She is concerned by the ethical implications of using hip protectors with a group who may not have the mental capacity to understand what they are or that they're even wearing them. She described how dementia – like the risk of falls - represents a wide spectrum, from early onset to a full, incapacitating condition. As such the requirements for each client can be very different. It is worth noting that in an ethics approved study, Garfinkel et al. (2008) found hip protectors to have high efficacy in preventing hip fractures in long-term care patients with dementia. However, "poor compliance" was defined as, "persistent refusal of patients to wear [hip protectors] despite repeated persuasion attempts by the team for at least one week", without elaborating on the reasons for their resistance. This oversight, and indeed the term 'patient', contrasts O'Brien's people-centred approach.

O’Brien is naturally concerned that the introduction of hip protectors to clients with dementia can be confusing and alien for them. However, if hip protectors designed for younger people at risk of fragility fractures were to become more mainstream (by reflecting the socio-cultural and lifestyle aspirations of the wearer) then their intervention for those in later life could eventually become more normalised. O’Brien suggested that active-agers could be persuaded to wear hip protectors if they had a sporty look, a theme reflected later in the interview with a fashion designer (see 4.1.3). Indeed, O’Brien noted that older people may be more prepared to wear this type of garment if it was related to sport, also providing comfort and forgiveness.

Through further discussion on how current hip protectors could be better designed, O’Brien observed the frequent need for her clients to wear incontinence pants or pads. The addition of hip protectors on top of these types of products adds another layer of clothing and complexity, impacting on comfort and ease of getting dressed or undressed. This suggests two further potential design opportunities: incontinence underwear with built-in hip protection, or hip protectors that operate separately from underwear.

With respect to the latter, O’Brien felt that the visual style of the HiP padded hip protector belt was a much more acceptable form of hip protection and noted that she would be happy to wear one herself. She also pointed out how a belt design reduces the need for frequent laundering (a significant advantage in a care home) and provided enough room to accommodate incontinence products.

The final discussion point led from O’Brien’s assertion that correct sizing and fitting of hip protectors is vital to their success at preventing hip fractures. For example, weight loss is a common aspect of ageing and physical decline in the very old. O’Brien noted that monitoring weight loss is important to ensure that hip protectors still fit correctly. She recalled one occasion when lifting a very frail, older woman, finding her hard-shell hip protector pads had pulled all the way up under her armpits! The need for a range of sizes to fit different shaped bodies is obvious, but hip protectors could also be adjustable, to accommodate changing body shapes, and include a means of ensuring their correct placement (e.g., a graphical device) when putting them on.

4.1.1.3 Reflection

The interview provided critical insights into prevention and protection from falls in care homes and established some key themes to further inform a product design specification. In summary, these include:

- Hip protectors must be as affordable as possible to be accessible to a wide proportion of the population on potentially low and fixed incomes.
- Hip protectors sensitively designed for more active users in a community setting could help them become more mainstream, normalising their use in later life. This could negate the issues met with older people with dementia unfamiliar with hip protectors and resistant to using them.
- Hip protector garments with a 'sporty look' could be more appealing to older users.
- Hip protectors that comfortably accommodate the use of incontinence products would be beneficial for some.
- Hip protectors worn over clothing reduce the need for frequent laundering.
- A belt type hip protector more easily accommodates incontinence underwear.
- Hip protectors must be available in a range of sizes but adjustability could help to accommodate changes in body size due to weight loss or gain.
- When dressing with a hip protector garment it would be beneficial to provide a means of visually indicating that the pads are positioned correctly.

4.1.2 Design probe with care home staff

Industry partner, Cornwall Care, invited me to visit one of their care homes, Mountford House, in Truro. A preliminary meeting took place with the care home manager to discuss the opportunities to work with the staff and residents as research participants. To begin with, I investigated the staff's experience of residents using hip protectors. This would have been followed up with focus groups or interviews with some of the residents too but, unfortunately, this plan was disrupted by the Covid-19 pandemic.

4.1.2.1 Methodology

I was given a limited opportunity to speak to staff for 30 minutes, coinciding with the changeover of carers between shifts. Although this provided some time for discussion, I was keen to explore the use of design probes to gather insights in a more reflective and less time-pressured way.

Design probes are tools used to gather data from research participants consisting of visual and tangible kits that include descriptive and exploratory tasks. The kits are left with participants to work with independently, then returned to the researcher for analysis later. Activities such as photography, journaling, or collage-making allow participants to observe, reflect and report on their experiences (Mattelmäki 2006). Design probes have evolved from 'cultural probe' methods developed by Gaver et al. (1999), who described them as an openly designer-centred alternative to studying users.

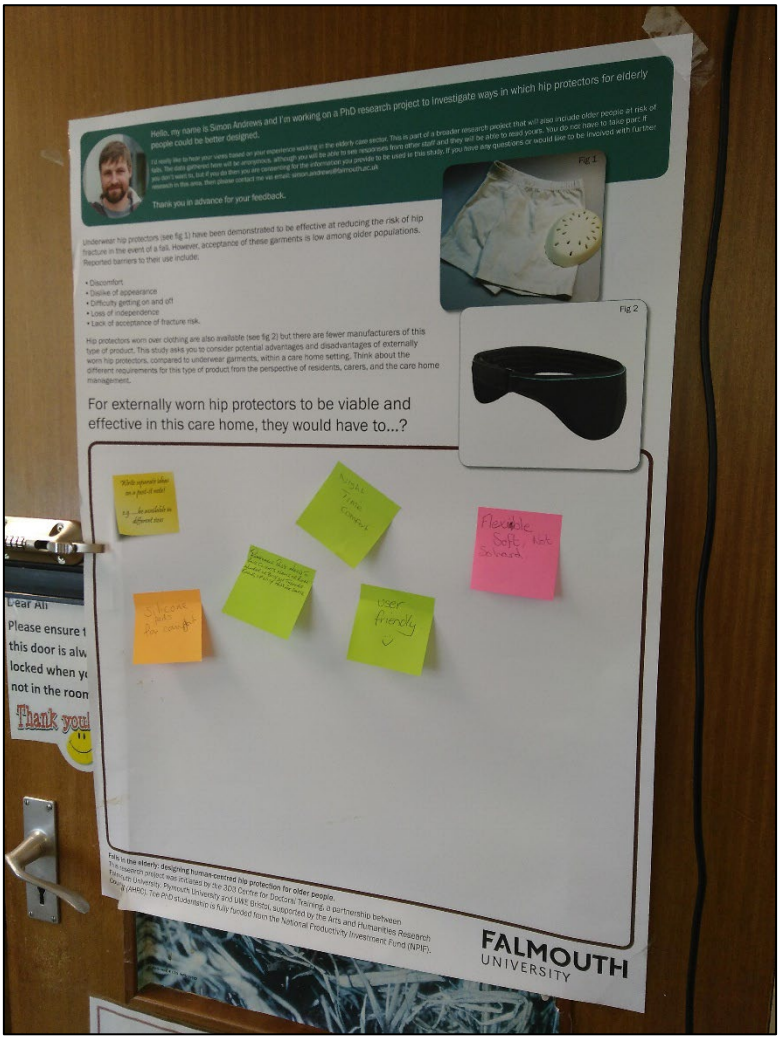


Figure 34: Design probe poster for Mountford House care home.

Reflecting on the contextual review, I was keen to understand the advantages and disadvantages of hip protectors worn under or over clothing. To explore this in a care home environment, I developed a simple design probe in the form of an interactive poster that outlined the differences between the two styles of hip protector (see Figure 34). These two hip protector garments were chosen for consistency as they had already been discussed with the gerontological physiotherapist, Pat O'Brien.

The poster posed an open question, asking: "for externally worn hip protectors to be viable and effective in this care home, they would have to…?". This engaged directly with the overall research question, how the design of existing hip protectors can be developed or challenged, and what other performance requirements exist beyond reducing hip fracture risk.

A dedicated space on the poster allowed participants to leave suggestions on Post-It notes, with an example response included on the poster as a prompt. Responses from the perspective of hip protector wearers, the carers, and the wider institution were invited to understand design criteria beyond the direct needs of the user.

The poster was pinned up in a social space used by the carers during breaks allowing them to contribute to the research at their convenience and reflecting on recent interactions with hip protectors during the working day. Gathering responses collectively also allowed participants to reflect on each other's comments to inspire further ideas.

Before setting up the design probe, I conducted a preliminary meeting during one of the 30-minute shift changeover periods. This was attended by six carers and one member of staff who worked in the laundry room, representing different experience of interaction with hip protectors. I gave an overview of the research project and presented the two examples of hip protectors shown on the poster. The staff were also shown the poster and given verbal instructions on the task. This was in addition to the written instructions on the poster to allow other staff who did not attend the preliminary meeting to contribute.

4.1.2.2 Results and discussion

The poster was in situ for two weeks but only gathered five responses (see Table 5). Explanations for the low response rate could be that staff were too busy to engage, or that they felt they had said all they needed to at the preliminary meeting. On reflection, the question could have been posed more simply (e.g., what are the advantages or disadvantages of the outerwear hip protector compared to the underwear hip protector?) and some staff may have felt intimidated.

Table 5: Participant responses to the design probe and interpretation.

Participant responses	Response interpretation
"Silicone pads for comfort"	Pads need to be softer to be more comfortable.
"Night time comfort"	The garment would need to be comfortable enough to wear in bed.
"Removable pads need to have client's name or room number or both on them as ending up with pads for shorts"	A labelling system is needed to identify the owner of the hip protector pads when they are separated from the garment for washing.
"User friendly"	The garment is comfortable and easy to put on and take off.
"Flexible soft, not hard"	Soft and flexible pads are more comfortable.

Most of the responses reinforce the importance of comfort and ease-of-use of hip protectors. This reflects how discomfort is the highest reported barrier to their use in the literature (Sims-Gould et al. 2014). Curiously, there were no comments about the visual appearance of hip protectors, perhaps illustrating how this is a low priority in a care home environment. However, the words "viable and effective" in the question may have biased pragmatic and function-orientated responses. Indeed, a labelling system so pads and garments can be easily reunited after washing, is a sensible and easily achievable suggestion.

A follow up discussion was conducted during a further 30-minute session with three of the carers who participated. Although this was not representative of all the participants views, and is recognised as a limitation in the study, the session allowed the themes presented to be expanded and discussed in more detail. The interpretation of the original comments was also validated here. I took notes and outlined five themes drawn from the discussion (see Table 6).

Table 6: Follow up discussion themes and comments.

Themes	• Comments
Underwear hip protectors (Fall Safe)	• Discomfort from heat, especially in summer. Lack of airflow. • Alternative needed for night time. Potential pressure sores, from pads at night. • Uncomfortable sitting in a chair as pads dig into wearer's sides. • Too many layers to pull down and up to go to the toilet. • Pads are too hard. • Manly, ugly and basic. • Two carers needed to help a resident into hip protectors. • No complaints about the look of underwear hip protectors. Worn under skirt or trousers.
Externally worn hip protectors (HiP)	• It's one thing; can't lose the pads. • It's size adjustable with velcro strap. • External hip protector can go over clothes so bigger clothes aren't needed to accommodate underwear hip protectors. A resident was described as wearing leggings with pads protruding prominently. • Wrap around. • Can be worn under or over, a bit like a money belt or bum bag.
Hip protector garments in general	• Pads need to be tight to keep in place. • Potential for extra-large sizing needed for bigger residents. • Normality of daily routine is important, relating to changing garments between night wear and day wear.
Residents living with dementia	• Danger of taking the hip protector off if it is visible. • Some residents living with dementia have little awareness of their own safety.
The institutional perspective	• Need to be easy to clean. Hip protectors worn externally would need to be washed less often. • Positive if care home can demonstrate falls and hip fracture reduction.

As with the original responses, most of the comments relating to underwear hip protectors are already discussed in the literature. The need for two carers to help a resident put on an underwear hip protector also reflects the difficulty of use experienced by others (e.g., Chan 2000; Patel et al. 2003; Woo et al. 2003; Doherty et al. 2004; Forsén et al. 2004; Ledsham et al. 2006; Tavener-Smith and De Vet 2006; O'Halloran et al. 2007; Bentzen et al. 2008b). The Fall Safe underwear hip

protector was deemed too bulky to be comfortable to be slept in. The carers were also concerned about pressure sores resulting from the pads. Skin becomes more fragile with age, making it more liable to tear compared to younger skin, especially if there are damp or shearing forces involved, e.g., sliding down a bed (Bryson 2015). It was noted that the normality of a daily routine was important and that garments worn for sleeping should be differentiated from clothes worn during the day. The opportunity for different designs for 'day wear' and 'night wear' hip protectors is clear.

Although underwear hip protectors were described as "manly, ugly and basic" by the carers themselves, there were also "no complaints" from residents about the look of them worn under a skirt or trousers. The perception was that the clients living with late-stage dementia, were unaware of their appearance or unconcerned. This presents an ethical question on the autonomy of these most vulnerable residents and echoes the concerns raised by Pat O'Brien. The safety of the residents is of the highest priority, and the carers reflected the earlier concerns that an externally worn hip protector could be more easily removed by the individual.

Some advantages for externally worn hip protectors were noted. The wrap around access of the garment (rather than having to pull up or down), and the potential for waist size adjustment using the Velcro strap, were suggested usability benefits compared to underwear hip protectors. Size adjustment to accommodate larger residents was particularly noted. It was suggested that the padded belt product could be worn under clothing instead, but wearing a hip protector over clothing negates the need for clothes sizes to be generous enough to accommodate underwear hip protectors. From an institutional perspective, it is advantageous that external hip protectors would need to be washed less frequently, and the one-piece product would prevent pads from being separated and lost.

4.1.2.3 Reflection

Overall, there was an interest in new types of hip protectors if they could be demonstrated to reduce hip fracture incidents in the care home. Although the design probe itself didn't yield the breadth of responses that were hoped for, the follow up discussion allowed these responses to be verified and expanded leading to a range of criteria to inform the design development. The small sample size is a limitation, so the findings must be triangulated with further qualitative research. The comparison to feedback on underwear hip protectors found in the wider literature is an encouraging indicator of the reliability of the data. The process also helped to contextualise the issues discussed earlier with

the gerontological physiotherapist, Pat O'Brien. The key themes that could inform the development of new types of hip protection are summarised here:

- Hip protectors must be comfortable to wear for extended periods of time with pads that don't dig in when sitting.
- Different types of hip protectors could be worn during the day and at night time, appropriate to the context of use but also reinforce normal daily routines.
- Hip protectors that were hidden from view and normalised into daily routines would be the least disruptive to residents living with dementia.
- Styles of hip protector, such as wrap around, could be advantageous for people with limited mobility/dexterity so they don't need to be pulled up and down.
- Hip protectors must be available in a range of sizes, but adjustability could also help to accommodate variation.
- A belt type hip protector negates the need for frequent laundering and integrated pads would prevent them from being separated and lost.

4.1.3 Interview with a fashion designer

The French fashion designer, Fanny Karst, has built her career designing clothes for older women. Inspired by her beloved grandmother and celebration of old age as a 'second youth', Karst's label, 'The Old Ladies Rebellion', embraces both a playful and graceful approach to fashion and ageing. She produces t-shirts emblazoned with provocative slogans such as, 'Not dead yet', as well as more sophisticated bespoke tailoring, combining elements of her Savile Row training, at Chittleborough & Morgan, with large digital prints (Karst 2020). Her fashion shows and photography shoots all feature older women and project a chic style in keeping with her location in downtown Manhattan, New York. Many of the women she works with are, or have been, models, to which Whitehorn (2009) notes, "maybe they aren't too typical of most of us groaning oldies but the clothes, nonetheless, do embody quite a few things that we like". Karst's work challenges the expectations of fashion for older women and explores the territory where playfulness and humour can be expressed through sophistication and glamour.

4.1.3.1 Methodology

The interview with Karst was semi-structured and I used a set of prompts to ensure the topics to be covered and questions were addressed (Milton and Rodgers 2013). This allowed the discussion to flow naturally, and additional unplanned questions could be asked to follow up on what was said. The interview was conducted over the telephone, due to Karst living in New York, and was recorded using Audacity, free, open source audio software (Audacity 2024). A transcript (see Appendix F) was generated later to provide a written record of the conversation for analysis.

The questions were developed to explore Karst's motivations for designing clothing specifically for older women and to draw from her experience any insights that could be effectively applied to the design of hip protector garments. Of particular interest, was Karst's position as a fashion designer and the role of fashion as communication. This engaged with the research question, particularly how sociocultural and lifestyle aspirations of older women can be appropriately represented through materials and aesthetics, and the meanings that could be communicated through hip protectors. The questions asked were:

- Can you tell me about your background and motivation to design clothing for older people?
- From your experience working with older clients, what do they perceive as wrong with clothing offered by retailers?
- Is there a particular design language that you adopt which is consciously different to an approach for younger audiences?
- Body size and shape changes as we age. Are there specific tailoring considerations for older bodies?
- What are the key challenges to designing for older people?
- Are your clients motivated to 'dress younger'? Is there a relationship between dress and inevitable aspects of ageing, such as reduced mobility (osteoporosis, arthritis, etc).

Through later listening to the recording of the interview, key responses were highlighted in the transcript that reflected the conceptual framework underpinning this research project and probed the three interrelated principles, outlined earlier. Much like the interview with Pat O'Brien, this helped to form criteria for the development of new types of hip protectors.

4.1.3.2 Interview analysis and discussion

Inspired by her mother and grandmother, Karst has a refreshing perspective on the positive attributes of getting older and the opportunities that presents. She says, "you can say whatever you want, wear whatever you want […] without the pressure of society, or having a job, of having to raise children. I don't know, I think it's a great age to really be wild and free". However, her notion of the freedom that older age provides, reflected in her care-free and glamourous clothing design, betrays the reality of ageing for many people. It must be noted that her work responds to a particular demographic of affluent, educated and fashion-savvy women. This is not to judge her work negatively but, for this research project, to understand that an awareness of intersectionality is needed to acknowledge the differences among potential hip protector users. The use of design personas to represent different types of people, reflecting their needs, lifestyle, and aspirations, will be an important part of this process discussed later (see 4.4).

With reference to existing clothing brands who, for example, use older models, Karst notes the taboo around ageing and the resistance of older women to engage with brands that identify as being specifically for older people. She refers to the push-back she experienced from some of her clients when she developed 'Old Ladies Rebellion', noting, "on the one side I want to say that it's for old people, but on the other side I can't because they're not going to want to be dressed in something that specialises in old people". This observation resonates with research indicating that hip protectors are associated with the frail and infirm, and the natural reluctance to be identified within that group (Tavener-Smith and De Vet 2006; Sims-Gould et al. 2014). Karst continues, "they never feel that they're old enough, which I completely understand", reflecting the 'mask of age' principle (Featherstone and Hepworth 1989) whereby the ageing body we see in the mirror 'masks' the unseen self, the person and age we really feel we are.

Karst argues that the stereotypical idea of what an 'old lady' would wear has changed very much in the last forty years. She believes that age has much less of an influence on fashion choices than other aspects of personal identity and lifestyle choices that transcend chronological age. "Psychologically they don't want to be perceived as old, they just want to blend in". Fundamentally, when considering the development of new hip protectors, it is vital that these garments have a familiarity, and align, aesthetically and ideologically, with clothing types understood and valued by the user. This cannot be said for most hip protectors currently available.

Karst's made-to-measure jackets and dresses capitalise on her skills as a tailor and training on Saville Row. Although the garments she designs are much more sophisticated than the t-shirts, by

specialising in large digital prints her work still conveys a sense of playfulness and pop culture. Karst notes that, “they come because they want a special dress, for a special occasion”. She discusses the difficulty designing for ageing bodies where individuals can change shape very differently as they get older. She does, however, note that our shoulders tend to become more hunched as we age, “so technically for design we give more fabric at the back, so it doesn’t pull, and then shrink it at the front”. Other interventions she describes include small shoulder pads to compensate sagging shoulders, and higher pockets to improve posture.

Karst is not known for fashion for medical care contexts, but she does take onboard individual user needs when designing made-to-measure garments. She is interested in, “resolving technical problems that are to do with their life. Not the fact that they’re old but the way they live”. Her bespoke clothing gives her the opportunity to understand her clients’ ageing bodies and design, “to make life very comfortable and to always have a sense of elegance – you know – even if you’re lying down in the bed, you should be a little bit elegant”. So, both the context of use, and her approach as a user-centred designer, is very different compared to the ready-to-wear context of her t-shirts.

The meanings evoked in Karst’s t-shirts are embodied through the design language of the physical garment, and the playful messages emblazoned across the front, such as ‘old is the new black’ and ‘not dead yet’. She discusses her approach with bold and strong messaging that attempts to break taboos. “I like to be a little bit provocative and humorous about these things”, she says. However, there is some tension between the ideas Karst discusses and how her work manifests. The t-shirts naturally convey a design language synonymous with youth, although the messaging on the t-shirts (and indeed, t-shirts with slogans are the preserve of the young) emphasises the wearer’s position as an older person. The irony of this dynamic is obviously part of the provocation. However, by taking the issue of ageing and adding a message such as ‘not dead yet’ across the front of the garment, Karst’s approach creates clothing exclusively for an older audience, and in doing so perhaps continues to reinforce an ageist concept that older people differentiate themselves, *by age*, through what they wear.

One area of particular interest to Karst, where lifestyle meets fashion, is sportswear, noting, “there’s a huge, huge market for sportswear for older people”. She comments on its practicality in terms of comfort and how the fabric stretches for a forgiving fit. However, she is frank about designing for “ladies who don’t exercise”, but embraces the meaning expressed through the “illusion and energy” of sportswear. She says, “Sportswear represents youth and activity. So I wanted to do that for old ladies… but a bit chic”. With so many big companies operating in this market, it’s a challenge for Karst

to break into it. She particularly admires the Japanese casual wear designer, manufacturer, and retailer, Uniqlo, noting how they have, “mastered clothes for older people”.

By understanding how the lifestyle aspirations of older people can be reflected in the meanings expressed through hip protectors, new products can be developed that respond to the psychological needs of these users. Receptivity to wearing hip protectors is key to their success as an effective method of reducing hip fractures. Karst frequently uses terms such as ‘cool’ and ‘chic’ which embody her approach to design leading to positive responses from her clients and many repeat customers. However, can hip protector garments be designed to be cool and chic too?

4.1.3.3 Reflection

The responses provided by Karst offer further insight into how the design of hip protectors could be improved. By reflecting the lifestyle and interests of hip protector users which relate to their life stage and context of use, new approaches can more sensitively accommodate their physical and psychological needs. There are clear opportunities to challenge the meanings associated with current hip protectors, shifting away from medical clothing contexts. Some critical themes emerged from the discussion, including:

- Karst’s work responds to a particular target audience. An awareness of intersectionality is needed to acknowledge the differences among potential hip protector users.
- Hip protector garments must meet the physical requirements of ageing bodies and the natural changes to body shape that occur.
- Hip protectors should have a familiarity, and align, aesthetically and ideologically, with clothing types understood and valued by the user.
- Sportswear is a rich area for investigation in terms of older markets and clothing that empowers its users.

4.2 Focus groups with active older people

Focus groups have been used in this project as a precursor to the development of more structured methods (Robson 2016) and Action Research. In this section, I discuss focus groups with active older

people, as a qualitative data collection method established during the 'discover' phase, to understand criteria for improving the design of hip protectors.

The contextual review identified the need for further investigation into attitudes towards hip protectors worn over clothing and the contexts where this style may be preferable to underwear products. This is part of a broader examination of criteria that would improve the receptivity and acceptance of hip protectors, to develop new products that reflect positive messages about ageing.

I recruited focus group participants from members of the exercise and balance classes run by industry partner, iCareiMove. This was an appropriate group to approach as their members are older people who are often referred to the company because they have fallen recently or become more vulnerable to falls. This also reflects the research question in terms of understanding who would benefit the most from wearing hip protectors.

4.2.1 Methodology

I held an informal pre-participation meeting straight after one of the exercise classes to introduce the research project and invite members of the class to take part in a pilot focus group. This was also found to be an effective approach by Seymour (2012) who ran similar pre-participation meetings to recruit research participants. Five women and two men were recruited for the study which was proportionately representative of the number of male and female members attending the class.

The overall group size reflects the six to ten participants recommended by (Morgan 1997). However, the analysis of attitudes towards fall prevention and protection by gender is very limited (Chang and Do 2015; Thilo et al. 2016; Criado-Perez 2019), so it was important to run two separate focus groups, female and male. I also felt that discussing an underwear product, and ease of use relating to toileting, were potentially sensitive topics that warranted separate groups. It was disappointing not to recruit an equal number of men and women, but not only were there fewer male class members, the men were less receptive to committing their time to the research. Despite the low number of participants, I decided to continue with the focus groups as a pilot and build on the experience for recruiting more men and women later. Unfortunately, the Covid-19 pandemic interrupted the substantial use of focus groups in this project.

The specific ages of the participants were not recorded. However, due to the nature of the class, all the participants were in later life stages, typically in their seventies and eighties. One younger female participant, however, was in her mid-sixties. The two focus groups were scheduled separately within

the month after the pre-participation meeting and, for convenience, took place after the exercise and balance class. The sessions were planned to last about 45 minutes, however, the male participants were only available for 15 minutes. Although this meant a much shorter discussion with the men, some useful points were still established, and they were also able to contribute to the same activities conducted with the female group. I recorded both sessions using Audacity audio software and written transcripts were generated using Otter, a web-based technology that uses artificial intelligence to transcribe audio recordings (Otter.ai 2024). The transcripts (see Appendix F) were corrected and validated when listening to the recordings as part of the review process.

Firstly, the participants were handed two hip protector examples to examine and compare. One product was the Fall Safe underwear hip protector and the other was the Protex HiP padded belt hip protector (both described in section 2.2.2). These were chosen to be representative of a hip protector worn under clothing compared to a hip protector that could be worn visibly over clothing. The same products were used for the design probe with care home staff and the interview with the gerontological physiotherapist to establish any correlation between the responses. The products are marketed towards men and women, so they were relevant to both the female and male focus groups. The sessions began with an open discussion on whether the participants would consider wearing either hip protector and, if so, in what circumstances. This particularly related to the research sub-question of how the design of existing hip protectors can be developed or challenged and the meanings communicated by these garments. The unstructured format allowed the conversations to develop organically and reveal a broader perspective on hip protectors in the context of ageing and accidental falls.

I then presented ten 13cm x 13cm cards, each showing a photograph of a different type of hip protector garment (see Figure 35). The products were selected from the 26 commercially available hip protectors studied by Laing et al. (2011), with the exception of the SafeHip Active which was supplemented as a padded belt type hip protector to replace the Anatech product no longer available. I chose ten examples for each focus group as a convenience sample to represent the range of visual styles. Of the ten selected, five were used with both the female and male focus groups. However, a further five were selected for each group based on gender-specific styling details. Following the principles of a card sort method (IDEO.org 2015), I then asked the participants to organise the cards from the most appealing hip protector to the least appealing. In addition to the final arrangement of the cards, the discussion that took place between the participants to decide on the ordering provided key insights into the rationale for their decisions. This engaged with aspects relating to performance requirements and the meanings communicated through hip protector garments.

Figure 35: Focus group participants engaging in the card sorting exercise.

I used notes taken during the sessions, the audio recordings, and the written transcripts to reflect on the discussion and draw out the salient points. In particular, the focus was on the attitudes towards existing hip protectors that could inform the development of better, more accepted, products.

4.2.2 Female focus group

Three of the participants showed an immediate preference towards the padded belt hip protector. This was even before establishing whether they would be prepared to wear one or not. However, it was clear that the visual appearance, in particular the black colour and similarity to a money belt, was preferrable to the underwear garment. The pads of the underwear hip protector were noted as a problem straight away with one participant commenting on how hard they felt. This is significant given that this product has 'soft' pads, rather than the hard-shell type found in competitor products such as Medilogics' KPH. Another participant added, "apart from being hard, it looks awful". The comparative sophistication of the padded belt hip protector was summed up by another woman who described it as looking, "more business like".

Four participants indicated that they would wear the padded belt hip protector but for some this would be context dependent. One commented that, "I can't imagine wearing anything with thick padding everyday". Another suggested it would be good to wear whilst gardening. The uncertainty of when it might be needed was also a deterrent with one of the women noting, "I wouldn't want to actively put that on just because I happened to be going into town and trip over a cobble". Similar to

Sims-Gould et al. (2014), a lack of acceptance of fracture risk was found in the group, with one participant in her eighties saying:

> "I would definitely wear one if it was necessary, or… I mean, at the moment I don't feel like it is, for my hips, but I would definitely know when to use it for my own safety."

Later, the same participant confessed to "a terrible fear of falling" and described a recent incident where she fell and injured her ankle. For the youngest participant, a woman in her sixties, the discipline required to wear a hip protector was informed by her own experience of wearing support garments for a medical condition:

> "I think you've got to wear it all day […] I wear a support belt. I get up, I have my shower, and then I put the support belt on. Then I go to bed and I take it off."

Most of the participants recalled recent incidents when they had fallen, with some sustaining serious injuries including fractures. It was noted that although a fractured hip was of grave concern, there could also be opportunities for garments to protect other parts of the body as well.

Although the participants expressed a more positive attitude to the appearance of the padded belt hip protector, most of the women agreed that they would wear it under their clothing with their own underwear pulled over the top. For the participant with experience of wearing support garments, this was a pragmatic decision to prevent the garment from riding upwards (thereby compromising its ability to protect the hips). This was also preferred, not only so that it was more discreet, but from the practical perspective of not having to remove the hip protector when using the toilet. This point was reinforced whilst discussing the underwear hip protector too. The participants all agreed that tight fitting fabric, such as Lycra, would make using the garment very difficult to pull up and down, and would not be acceptable.

The negative perceptions of the underwear hip protector were also informed by a sense that – although the product is marketed to both women and men – it has a masculine appearance. One woman noted, "it looks masculine […] They look like men's pants and totally off putting". Another participant commented that she would wear an underwear hip protector, "but it would have to be feminine". It is interesting to note that none of the participants suggested that the padded belt hip protector looked too masculine, even those who would prefer to wear it under their clothes next to their underwear. This would suggest that the padded belt was perceived as an altogether different type of garment, disassociated from the cultural norms of gendered clothing, in particular underwear.

It was noted that the padded belt hip protector feels physically lighter than the underwear garment, primarily due to the weight and bulk of the foam pads of the former. The weight, and physical presence, of the underwear garment was a concern shared across the group. Paradoxically, there was also concern that the lightness of the padded belt product equated to it being less effective at preventing hip fractures. One participant expressed this concern:

> "That doesn't look like it's got much resilience against someone who is heavy, like me, going down onto that. Would that protect my hip?"

Striking the right balance between lightness and comfort, and a perception of the product's resilience and effectiveness, must be a key consideration in the development of new types of hip protectors. Similarly, hip protectors that are feminine in style and can be worn discretely were more acceptable with this group.

When the participants were given the ten cards showing the different types of hip protectors, they spent about three minutes discussing and ordering them from most to least appealing (see Figure 36). They grouped the hip protectors thematically based on their observations, resulting in four tiers of cards with the two most equally favoured hip protectors at the top, and three equally disfavoured at the bottom.

Following the earlier discussion relating to ease of use, the group immediately gravitated towards the hip protectors that are open at the bottom and do not need to be pulled down when using the toilet. The SafeHip Active was appealing for this reason, described by one of the participants as looking "like a girdle". The wrap-around style with Velcro fastening also appealed to the group. Similarly, the Hipsaver was favoured as the participants assumed it did not have a gusset (although it actually does). Interestingly, although the HipEase has similar attributes it was dismissed with little discussion due to its visual appearance. "I think that's awful", noted one participant, with another responding, "that's dreadful".

The texture of the bulging pads visible on the Hip Shield was also unappealing, being described as "spongy" and "horrible". There was no discussion about the Secure, only that it was described as "horrid". With loose-fitting shorts and a wide, branded elasticated waistband, this product is noticeable as the most masculine looking garment on the range of cards. It is worth noting, however, that Secure is not modelled on a person and the HipEase is styled on top of another garment of contrasting colour, both of which could have affected their perception. The similarity of some of the other garments was observed although the appearance of the HIPS was noted as being "nicely shaped" but with the disadvantage that, "you've got to pull it up and down".

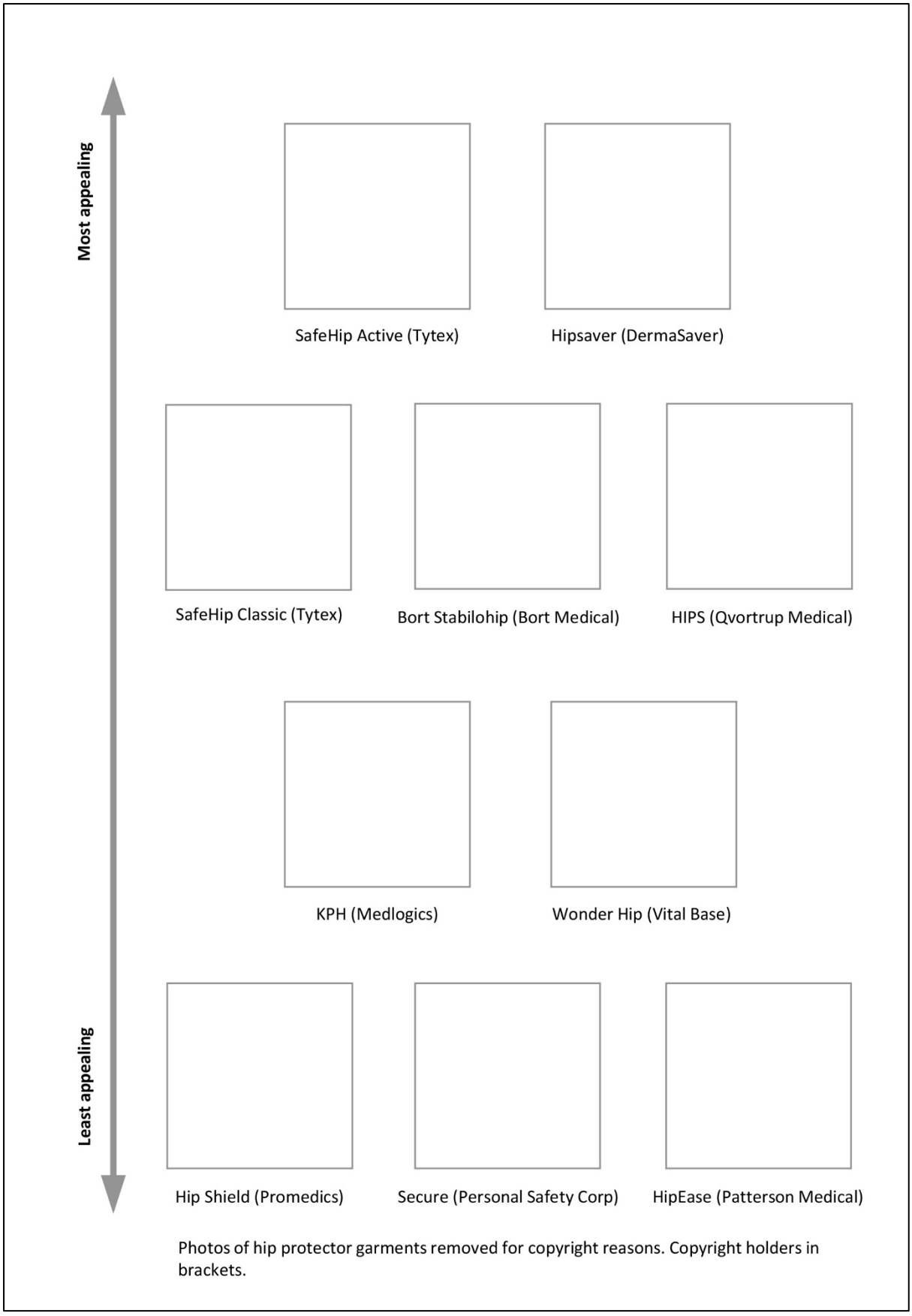


Figure 36: Hip protector images ordered from most appealing (top) to least appealing (bottom) by female focus group.

The perceived effectiveness of the hip protectors was also discussed. Although the participants thought the Bort Stabliohip was one of the most visually appealing hip protectors, one of the women commented, “that doesn’t look as if it’ll protect very much, does it?”. Conversely, another participant regarded the Hipsaver as “quite bulky” and disagreed that the pads needed to be thicker to be effective. In this respect, two of the women disagreed on whether the Hipsaver would be visible under clothing, demonstrating a certain degree of compromise in seeking a consensus for the final ordering of the cards.

The thickness of the pads was not the only concern regarding their effectiveness. The participant in favour of thinner pads was also put off by the KPH hip protector. She commented:

> “I don’t like those because you slip them in and I don’t think they’re in the right place, and they’re not wide enough.”

Similarly, this reflects earlier discussions regarding the extent of protection offered by these types of garments and the conviction of the user that the product would “do the job”.

4.2.3 Male focus group

The initial discussion with the male participants flowed much less naturally than with the female group. As there were only two men taking part there were fewer voices and perhaps they felt more self-conscious about expressing their views. The limited time made available for the discussion may also have been indicative of two participants who didn’t really feel they had much to contribute to the topic. Although both participants were regular attendees to the exercise and balance class, neither felt at particular risk of falling or had considered wearing a hip protector. One of the men commented, “I never thought about it, quite honestly”. There was, however, some recognition of a later need: “the older we get the more fragile you become, […] the more unsteady you become”.

Despite the limited breadth of discussion, there were some points, expressed more concisely, that reflected the attitudes shared with the female group. For example, on reviewing the underwear hip protector one of the participants wryly commented, “it's not really a fashion garment, is it”, but neither participant vocalised any concern in terms of the thickness of the pads or the type of fabric. Similarly, when the padded belt hip protector was introduced, one of the men immediately questioned why it would be worn over clothing: “it seems to me, cosmetically, you might put it underneath your trousers”. This reflects the preference shown in the female group, although more so in terms of discretion rather than any practical reason. The comparative slimness of the protective

pads on the padded belt was also noted with a similar concern over its effectiveness at preventing a fractured hip.

For one of the participants, the principle of the underwear hip protector could be extended to shorts more generally. This is reflective of the Hipsaver shorts manufactured by DermaSaver, discussed earlier in the contextual review (see 2.2.2). In this instance, the participant felt, “it would be more accepted, in a sense, in the summertime”, although he also noted, “I'm not likely to end up wearing shorts anyway [...] I don't wear shorts anymore”. Regardless of attitudes towards wearing shorts, unsurprisingly, neither participant was concerned by the masculine appearance of the underwear hip protector.

It was difficult to discern any particularly strong feelings of like or dislike relating to either garment. However, it can be said that discretion (either by hiding the hip protector under clothes or disguising it as a different garment) and pad efficacy were priorities for the male participants. Although the initial discussion was shorter than the female group, the male participants spent more time (about 5 minutes) discussing the ten cards. Like the female group, the men also found some of the hip protector examples to be of equal standing. As a result, they settled on three tiers of cards with the three most equally favoured hip protectors at the top and three equally disfavoured at the bottom (see Figure 37). A central row of four cards represented those that were viewed comparably with little to distinguish them in terms of priority of preference. Most notably, both groups perceived the SafeHip Active to be one of the most appealing, and the HipEase to be one of the least appealing.

Despite articulating that some of the hip protectors are designed for both men and women, most of the garments modelled on female bodies seemed to be instinctively less appealing to the male participants. For example, the HipEase and Bort Stabiliohip were regarded as, “ladies’ ones”. The Posey and ComfiHips products were immediately identified as most appealing by one of the participants who described them as “gents’ garments”. Hip protector shorts with a fly opening were seen as advantageous for using the toilet but perhaps also helped to normalise the perception of these garments as ordinary underwear.

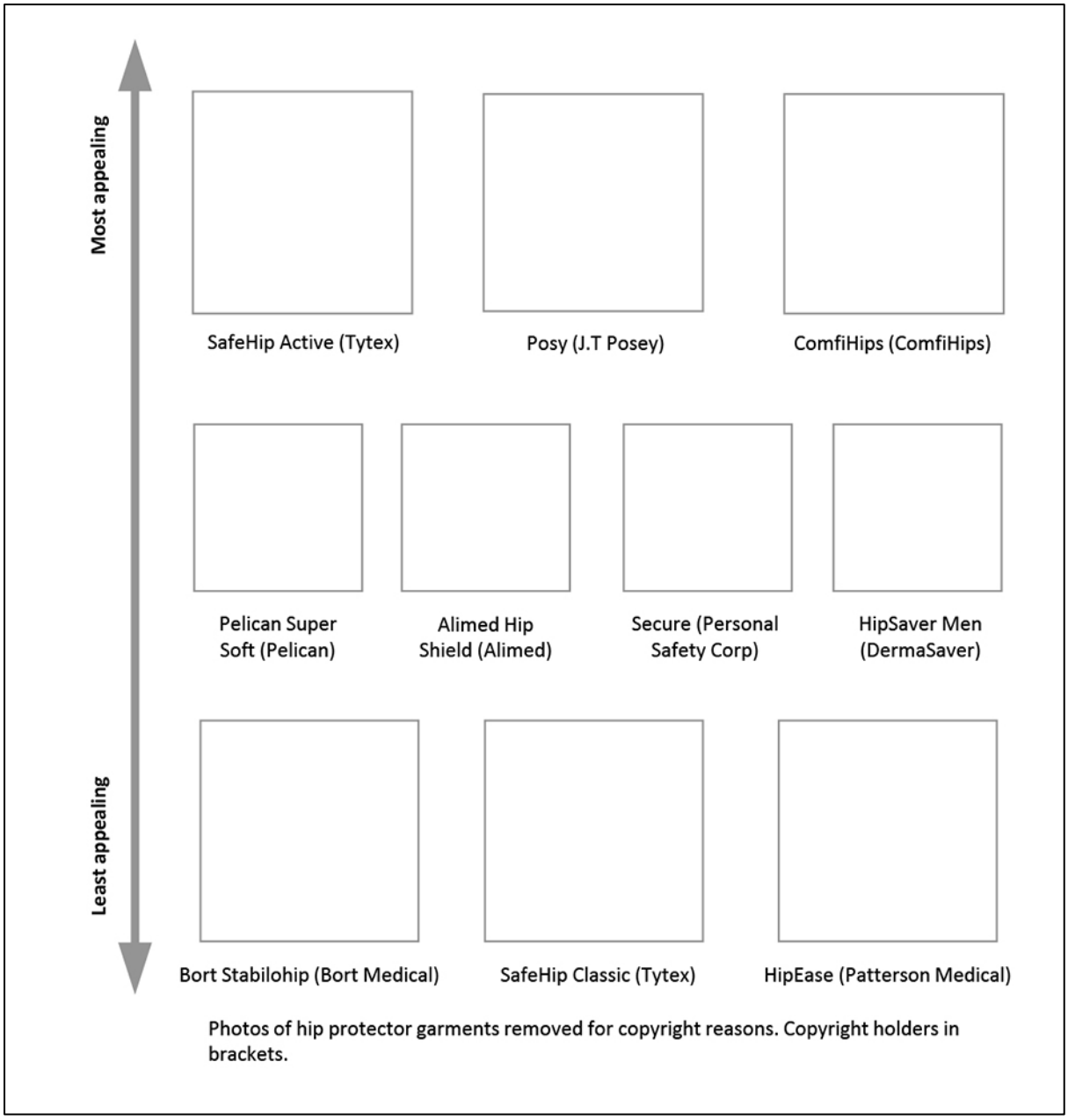


Figure 37: Hip protector images ordered from most appealing (top) to least appealing (bottom) by male focus group.

The SafeHip Active garment (modelled on a woman) did appeal to the men primarily due to its "deeper" padding. The thickness, and related efficacy, of the pads was established as a key priority for the male participants. Unlike the female group, the men were less concerned with the appearance of the hip protector, or how it may alter the outer appearance of the wearer, when discussing the cards. One of the participants argued:

> "I think if you feel you're in danger of falling you wear the most protection you can. And if you feel that 'well, it's not going to happen to me', you're not worried."

This attitude was reflected in the analysis of the Bort Stabliohip, described as looking, “very flimsy” and with “no substance”, a point echoed by some of the female participants.

Also like the female group, there was some consideration to ease of use. The HipEase was perceived to be potentially problematic in this respect, noting, “the least fussy you have, the better; easier to pull it off”. The men also noted the respective positioning of the pads and how effective they would be at preventing a fracture. For example, the pads on the SafeHip Classic were perceived to be, “a bit low […] below the hip, I think”.

4.2.4 Reflection

It was disappointing not to recruit more participants for this first round of focus groups (especially men), but I was happy to treat it as a pilot. It was frustrating that the Covid-19 pandemic then disrupted the opportunity to build on this starting point.

Although a more detailed review and discussion took place with the female group, the views of both the women and men were broadly aligned. Both groups were concerned with ease of use, especially going to the toilet. Also, both male and female participants wanted gendered products relating to cultural norms, although this point was particularly made by the women who noted the masculinity of some of the hip protector examples.

The female group preferred a padded belt type hip protector, but despite the potential advantages of this being worn over clothing, were generally of the view that it should be hidden under clothes or disguised in some other way. The men were less forthright in expressing a preference between the two hip protector samples but were clearly also motivated by discretion. However, this seemed less important to them than the efficacy of the product, even if thicker pads were more visually prominent.

Both the male and female participants identified the SafeHip Active product as ‘most appealing’, demonstrating receptivity towards padded belt type hip protectors, whether they’re worn under or over other clothing. The black colour of this garment may have also been a positive influence due to its similar appearance to the Protex HiP padded belt garment discussed. However, a careful balance must be struck to develop hip protection that is lightweight and comfortable, which can be discreet whilst also providing the user with reassurance of its resilience and efficacy.

The key themes that could inform the development of new types of hip protection are summarised here:

- Hip protectors should be easy to put on and take off, especially in relation to using the toilet.
- New designs of hip protectors should consider cultural norms of gendered clothing, especially relating to underwear garments.
- There is potential for padded belt type hip protectors that can be worn more discretely under clothing.
- Hip protectors should be lightweight and comfortable but also evoke confidence that they are effective.

4.3 Online survey: Perceptions of fall risk and attitudes towards hip protectors

The online survey examined whether gender, age, history of hip fracture, and the respondents' own perceived risk of falls, influence attitudes towards hip protectors and preferences in their design. An understanding of these variables would help to inform the development of hip protectors for different types of users whose expectations and needs may differ considerably.

The literature examining barriers towards the use of hip protectors tends to focus on care home populations as they are at higher risk of falls and provide convenient groups for sampling (see 2.2.3). Current underwear type hip protectors are shown to slightly reduce the number of hip fractures in care homes. However, due to poor acceptance, the provision of hip protectors, "probably have little or no effect on the incidence of hip fractures in older people who remain ambulant in the community." (Santesso et al. 2014). It is therefore concerning that, in the UK, about three quarters of patients admitted to hospital with a hip fracture are community residents, and from this group about 10-20% ultimately move to institutional care (National Institute for Health and Care Excellence 2013).

To engage with community dwelling populations at risk of hip fracture, the online survey was directed towards members of the Royal Osteoporosis Society (ROS). They are an appropriate sample group for the research as people with osteoporosis, a disease that causes low bone mass and deterioration of bone tissue, are at higher risk of fragility fractures (National Institute for Health and Care Excellence 2017). The ROS hosted a link to the online survey on their website (Royal Osteoporosis Society 2021), and shared the link across their social media platforms, Facebook and Twitter.

4.3.1 Sample

A total of 156 people responded to the online survey, 146 of whom were women. This gender bias is comparable to a larger online survey of ROS members by Paskins et al. (2017) who found within their 1188 respondents, 87.4% (n=1038) were female, 7.4% (n=88) male, and 5.2% (n=62) did not respond. The high proportion of female respondents reflects the higher instances of osteoporosis found in women. It may also simply indicate that women are more highly represented within the ROS membership. The significant bias towards women meant it was not possible to establish any meaningful correlation between gender and attitudes towards hip protectors. The analysis of responses only focused on women as the target group, with further research needed to reach more male participants.

Although the total number of responses to the online survey was significantly less than the survey conducted by Paskins et al. (2017), it is encouraging that the overall demographic profile is similar as this demonstrates the smaller sample is proportionally representative of ROS members. Most importantly, this group are at higher risk of fragility fractures and are potential primary users of hip protector products now or in the future. However, the relatively small sample size jeopardises the statistical reliability of the data, so the findings are interpreted in alliance with the earlier qualitative research.

I clustered the data by self-reported risk of accidental fall (see Table 7), to gain further insights into the demographics of the survey sample. Most of the respondents were aged between 50 and 79 with almost half in the 60 – 69 group (n=67). The sample is also biased towards women living with osteoporosis who consider themselves being at higher risk of an accidental fall compared to earlier in their adult life. Feeling more vulnerable due to having osteoporosis is a significant factor influencing perception of fall risk. However, experience of a previous fall has strongly influenced the group who feel most at risk of an accidental fall. Older age also correlates to perception of fall risk, making it difficult to differentiate between age and risk of fall in terms of attitudes towards hip protectors. A larger sample would be a way of overcoming this but is outside the scope of this study. Similarly, only 12 of the respondents had already experienced a fractured hip. Due to the small sample, it is difficult to discern any meaningful link between a history of hip fracture and attitudes towards hip protectors. However, most of the respondents who had previously broken their hip reported being at the highest risk of an accidental fall. Overall, due to sample size, age was the only reliable variable to analyse and interpret the data.

Table 7: Characteristics of female online survey respondents (n=146) clustered by self-reported risk of accidental fall.

Self-reported risk of an accidental fall [a]	**Extremely true (%)**	**Somewhat true (%)**	**Slightly true (%)**	**Not true at all (%)**
Total number of women, n	72 (100)	44 (100)	22 (100)	8 (100)
Age:				
39 or under	2 (3)	0 (0)	0 (0)	0 (0)
40 – 49	4 (6)	0 (0)	2 (9)	1 (13)
50 – 59	8 (11)	11 (25)	7 (32)	4 (50)
60 – 69	35 (49)	19 (43)	10 (45)	3 (38)
70 – 79	21 (29)	13 (30)	3 (14)	0 (0)
80 – 89	1 (1)	1 (2)	0 (0)	0 (0)
90 or over	1 (1)	0 (0)	0 (0)	0 (0)
Diagnosed with osteoporosis:				
Yes	69 (96)	42 (95)	14 (64)	6 (75)
No	3 (4)	2 (5)	8 (36)	2 (25)
Prefer not to say	0 (0)	0 (0)	0 (0)	0 (0)
History of hip fracture:				
Yes	8 (11)	3 (7)	0 (0)	1 (12)
No	64 (89)	41 (93)	22 (100)	7 (88)
Prefer not to say	0 (0)	0 (0)	0 (0)	0 (0)
Reason for feeling at risk of falls [b]:				
I feel more vulnerable because I have osteoporosis	59	27	9	n/a
As I have become older I sometimes feel less stable when walking or standing	31	10	4	n/a
I have other health conditions that affect my balance or mobility	22	8	1	n/a
I have fallen before which has affected my confidence	46	15	7	n/a
Other [c]	9	7	6	n/a

[a] Responding to the question, "I consider myself more at risk of an accidental fall now compared to earlier on in my adult life"

[b] Participants could pick multiple responses, hence total does not equal n

[c] Responses elaborated on chosen reasons, including other self-reported fractures and poor balance due to medication or age. Weight was not reported as a factor.

4.3.2 Methodology

I adopted an online survey method for convenience and to accommodate social distancing rules due to the pandemic. The survey was presented through Microsoft Forms software (Microsoft 2024) which automatically adjusts the screen layout to accommodate the device it is being viewed on (e.g. smart phone, tablet or computer). There were 35 items consisting of nominal and ordinal questions. Closed ended questions were occasionally followed by open ended questions to allow respondents to qualify their answers. Robson (2016) notes the use of visual aids as one of the advantages of internet-based surveys, and photographs of existing hip protectors were included to gain responses related to their appearance. Dillman et al. (2014) provide useful guidelines for choosing words and forming questions which I adopted in the planning of the survey.

I presented a draft survey to participants at Falmouth University's Summer Research Student Symposium in July 2020. The discussion and review of responses informed the development of the survey, primarily so that it more clearly reflected the PhD research questions. A pilot survey was then shared with my own social and professional network as a convenience sample. This gathered 38 responses and proved the viability of the questions and survey design. The survey consisted of three parts covering key themes that reflect the broader research questions of the PhD investigation (see Table 8). The survey questions are presented in Appendix H.

In part 1, attitudes towards underwear and externally worn hip protectors were explored using the same two products discussed in earlier focus groups and the interview with Pat O'Brien. Branding was removed from the image of the belt hip protector to provide a fair comparison the unbranded underwear garment. I conducted a quantitative analysis of responses to measure receptivity towards these products. Age was explored as a variable to investigate if preferences for hip protectors that are visible or hidden were contingent with older or younger populations.

To explore the meanings that hip protectors communicate as garments, respondents were asked to choose three words they felt best described the products' appearance. The words chosen were differentiated between those from respondents who agreed or strongly agreed they liked the appearance, those who neither agreed or disagreed, and those who disagreed or strongly disagreed. I have presented this data as a 'word cloud', using free online software (FreeWordCloudGenerator.com 2024), to visualise the range of words and number of instances. Word clouds are a novel and reader-friendly approach for analysis and presentation of qualitative data (Mathews et al. 2015).

If respondents agreed that they liked the appearance of either hip protector, a branching open question asked them to identify what it was that appealed to them (see questions 12 and 20). Similarly, respondents who indicated that they did not like its appearance were asked to list up to three changes to the appearance of the product that would make it more appealing to them (see questions 13 and 21). The feedback from both questions help to contextualise the themes interpreted from the word clouds.

Table 8: Themes, research questions and items on the online survey.

Theme	Research Question	Item on Survey
Part 1 - Attitudes towards underwear and outerwear hip protectors	Which people are most at risk of hip fracture?	See questions 1-6: demographic information, self-reported fall risk and reasons.
	What precedents exist for the design of hip protector products and how can these be developed or challenged?	See questions 7-13 and 17-21: evaluation of underwear and padded belt hip protectors noting what is liked or would be changed about their appearance. Question 25 explores preferences between the two products.
	What meanings do hip protectors communicate as garments?	See questions 14-16 and 22-24: three words to describe the appearance of underwear and padded belt hip protectors.
	Beyond reducing hip fracture risk, what are other performance requirements exist, for people and planet, across the lifecycle of the product?	See question 25: preferences between hip protectors worn under or over clothing.
Part 2 - Attitudes towards inflatable hip protectors	Beyond reducing hip fracture risk, what are other performance requirements exist, for people and planet, across the lifecycle of the product?	See questions 26-31: attitudes towards cost, charging batteries, and replacing compressed gas cartridges of inflatable hip protectors.
Part 3 - Re-thinking hip protection	What are [the sociocultural and lifestyle] aspirations and how can they be appropriately represented through material and aesthetic judgements?	See question 32-33: context of use of hip protectors and style preferences.
	Beyond reducing hip fracture risk, what are other performance requirements exist, for people and planet, across the lifecycle of the product?	See question 34: prioritising design criteria for existing and new types of hip protectors.

I systematically analysed the responses using ATLAS.ti qualitative data analysis software (Scientific Software Development GmbH 2024) and coded according to statements that qualify as design criteria. Norman's (2005) three levels of design interaction – visceral, behavioural, and reflective – provided a meaningful way of organising the codes into distinct categories. The visceral level of a design is concerned with its visual appearance and our immediate response to it. This is where the meanings of an object are read and interpreted. I categorised the codes generated from comments about the visual appearance of the hip protectors into the 'visceral group'. The behavioural level relates to the effectiveness of use of an object, how well it fulfils its intended purpose. I categorised the codes relating to the perceived function or performance of the hip protectors into the 'behavioural group'. Finally, the reflective level is where the meanings of an object are placed in the context of the user; what does using or owning the object 'say' about the user? How does it reflect their self-image, status or invoke personal meaning? I categorised the codes related to comments about how the hip protector would make an individual look (especially to others) and feel into the 'reflective group'. Grouping the codes into visceral, behavioural, and reflective categories focused where to prioritise changes to the appearance of the hip protector: how it looks, how it appears to function, or the users' perception of how they would appear to others when wearing it. These responses were clustered by age to investigate whether the design priorities, and focus for necessary change, are different between younger and older respondents.

Question 25 explored the preferences between hip protectors worn under or other clothing and was added to contextualise the earlier responses towards these two different types of products.

Part 2 explored inflatable hip protectors that consist of airbags which automatically deploy if the wearer starts to fall. Manufacturers of these products, such as Tango and Wolk, have been involved in clinical trials that indicate improved efficacy compared with underwear hip protectors when used in long-term care facilities (Tarbert and Singhatat 2021; Nemeth et al. 2022). Wolk's independent product testing demonstrates that, "the impact reduction is between 93% - 98%. In comparison, traditional hip pads reduce the impact by 5% - 30%" (Wolk 2024c). Although these early results are promising in terms of user compliance and reduction of hip fractures, there are yet to be any studies that report on user expectations or attitudes towards these new types of hip protectors.

The potential barriers to using an airbag hip protector are overall product cost, the requirement to recharge batteries, and the requirement to replace compressed gas cartridges after the airbags are deployed. I designed survey questions 26 to 31 to specifically explore these areas. The questions were preceded by a statement describing airbag hip protectors and the higher level of protection they offer compared to traditional hip protectors. The extra expense (around ten times as much as

underwear or padded belt hip protectors), use of rechargeable batteries and compressed gas cartridges were also key points presented to respondents.

Quantitative data relating to positive, negative, and neutral attitudes (yes, no, and maybe responses) towards the three scenarios posed in the questions were analysed. In each instance, the closed-ended question was followed by asking respondents to explain the reason for their last answer. As with earlier analysis, these responses were systematically analysed using ATLAS.ti qualitative data analysis software (Scientific Software Development GmbH 2024) and coded. I interpreted the data by reviewing the frequency of codes and patterns of responses.

Part 3 of the survey explored lifestyle, with questions about the likely scenarios for hip protector use, preferences for clothing styles, and how these might relate to the design of hip protectors. A range of potential scenarios where hip protectors might be worn were derived through earlier discussions with focus group participants. These scenarios formed a closed-ended survey question (question 32) where respondents were asked when they would most likely wear a hip protector. I conducted a quantitative analysis of responses with age used again as a variable to investigate if scenarios of use for hip protectors differed between older or younger populations.

Question 33 asked respondents to describe their preferred clothing style for a hip protector worn visibly over their clothes or integrated into outer garment layers. The closed-ended question offered a choice of styles derived mostly from web-based fashion sources such as Schuessler (2020). The term ‘medical’ was added to the style list to test the hypothesis that clothing that reflected hospital or care contexts would not be popular. A total of 14 words were chosen consisting of pairs with contrasting meanings, such as ‘masculine’ and ‘feminine’ or ‘bold’ and ‘understated’. Some words with similar meaning, such as ‘sophisticated’ and ‘elegant’ or ‘casual’ and ‘relaxed’ were also used to determine the strength of feeling towards a particular style, i.e., if a respondent used one or both words. However, the list of styles was presented alphabetically to avoid inferring any associations between the words. To increase the overall sample size of women, the data from the ROS survey (women, n=146) was combined with the data from the pilot survey (women, n=25). This had no effect on the overall distribution of style preferences but helped to increase the group sizes when clustering by age. The pilot survey data is from the general population, covering the same age ranges, but not specifically ROS members. As the question is related to broader issues of fashion preferences, this should have no bearing on the quality of results. As before, I conducted quantitative analysis of responses to examine preferences on the visual style of hip in relation to age.

The final question gauged the priorities respondents placed on certain criteria for hip protector design. Four criteria were presented with question 34, and respondents were asked to place them in

order from most important to least important. The criteria were derived from discussions about existing hip protectors with focus group participants, and relate to comfort, ease of use, effect on personal appearance, and cost. The efficacy at preventing hip fractures was also considered as a criterion but it was assumed this would naturally be the highest priority. On reflection, however, it would have been helpful to see if any respondents felt that the level of protection might be sacrificed for greater comfort or aesthetics, for example. Clustering the responses by age provided an indication of how the importance of different design criteria may vary between younger and older hip protector users. Overall, the responses have helped to shape an understanding of the contexts where hip protectors might be used and inform new ideas for the design of hip protectors.

I included a final, optional, open-ended question to allow respondents to add any further comments on the design of hip protectors or their preferences between them. The responses gathered here generally reinforced or added further context to earlier responses. It was therefore not analysed or interpreted in detail, although some of this data was used to shape the personas discussed later (see 4.4).

4.3.3 Attitudes towards underwear and outerwear hip protectors (Part 1)

Of the 138 women who consider themselves at risk of an accidental fall, 30% (n=42) said they would wear the underwear hip protector (see Figure 38). However, a further 49 women (34% of the total sample) anticipated that they would wear an underwear hip protector at a time in the future when they felt at greater risk of falling. The perceived willingness to wear the garment is, however, not reflected in the attitudes towards its appearance. In response to the statement, “I like the appearance of the underwear hip protector example”, only 6% (n=8) agreed that they liked its appearance and only 1 respondent strongly agreed. 75% (n=110) of women either disagreed or strongly disagreed that they liked the appearance (see Figure 39).

The padded belt hip protector was more accepted, both in terms of receptivity to wearing it and in attitude towards its appearance. 93 women said they would wear the example shown, representing 67% of the survey sample who consider themselves at risk of an accidental fall (see Figure 38). However, a total of 117 women, 80% of the survey sample, would be prepared to wear the padded belt hip protector now, or at some time in the future. The greater receptivity was also reflected in the responses regarding its appearance. In response to the statement, “I like the appearance of the padded belt hip protector example”, 32% (n=46) agreed and 8% (n=12) strongly agreed (see Figure

39). However, it is worth noting that the pattern of disliking the appearance of the underwear hip protector is not inversely true for the padded belt.

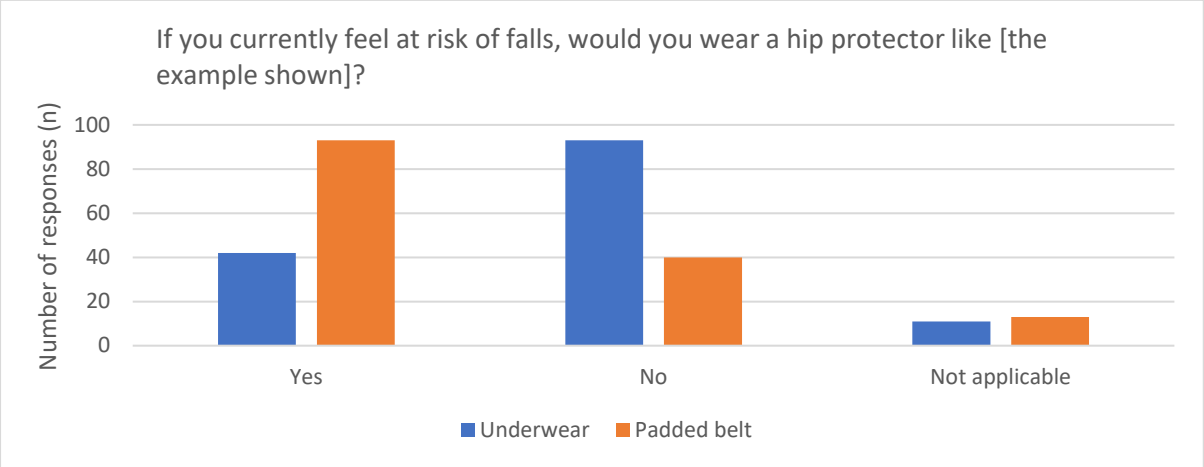


Figure 38: Comparing receptivity towards wearing an underwear or padded belt hip protector.

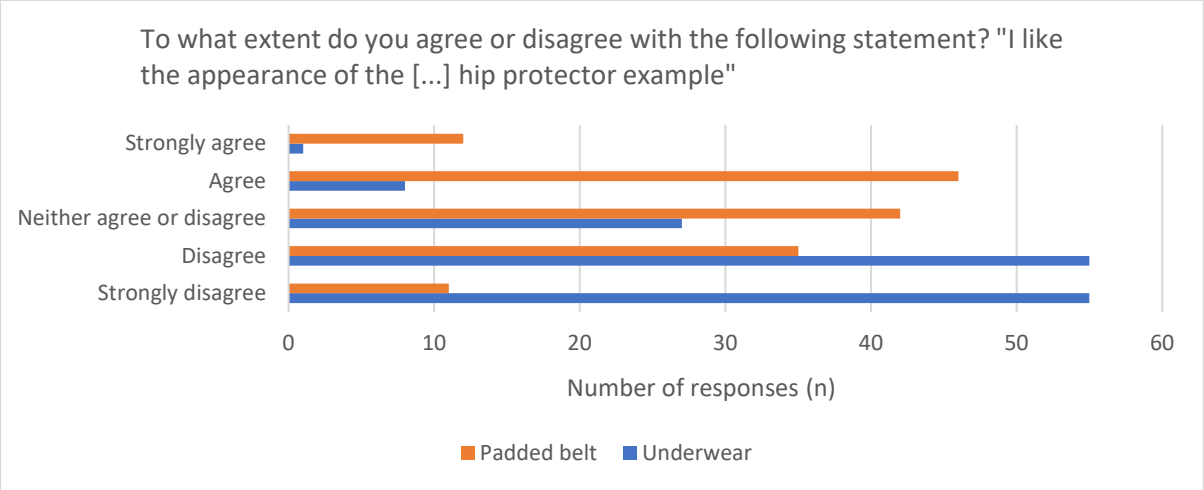


Figure 39: Comparing receptivity towards the appearance of the underwear and padded belt hip protectors

4.3.3.1 Word cloud analysis

The meanings interpreted through hip protectors can be explored by analysing the three words respondents chose to describe the appearance of the garments. These have been differentiated from respondents who agreed or strongly agreed they liked the appearance, those who neither agreed or disagreed, and those who strongly disagreed or strongly disagreed.

With the underwear hip protector (see Table 9), the word ‘bulky’ appears significantly across all three word clouds. This suggests the bulkiness of the garment is seen positively by some (e.g., in terms of the associated padding and security that brings), and negatively by others (e.g., relating to perceived discomfort or an unflattering effect on the body). The other positive attributes of the ‘agree and strongly agree’ group mostly relate to the perceived protection of the garment with terms used such as ‘supportive’ and ‘reassuring’. However, it is ironic that some positive aspects described by this group (e.g., ‘unobtrusive’, ‘discreet’, ‘hidden’) are perceived in the opposite and negative way by the other groups. With such a small sample, it’s difficult to determine any demographic trends with the ‘agree and strongly agree’ group.

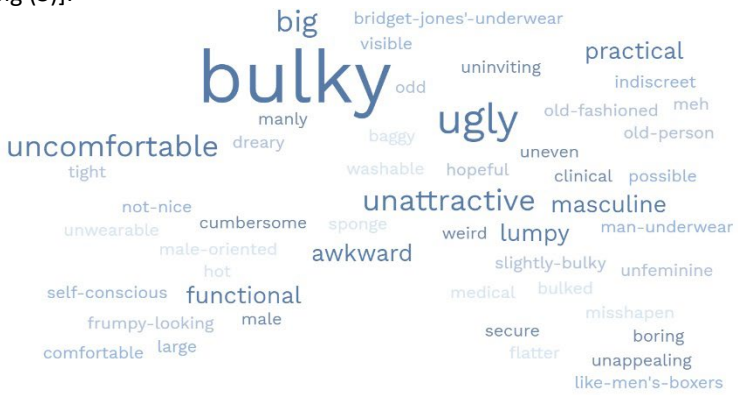
There is little to differentiate the tone of the underwear hip protector ‘neither agree or disagree’ group from the ‘disagree and strongly disagree’ group. In both instances ‘bulky’, ‘ugly’ and ‘uncomfortable’ appear as the top three words chosen to describe the garment. Both groups also use terms such as ‘unfeminine’ or ‘masculine’ and refer to male underwear. This aligns with Topo and Iltanen-Tahkavuori's (2010) framework of patient clothing (see 2.1.2), indicating a demand for garments that are in accordance with gender specific cultural norms. The resistance towards ‘patient-scripted clothing’ is also demonstrated by both groups citing words such as ‘medical’, ‘surgical’ and ‘clinical’.

Terms like ‘comical’, ridiculous’, and ‘yuck’, also embody meanings that position the garment outside cultural norms. Whereas ‘elderly’, ‘for-old-people’, and ‘old-person’, imply a visual language tied to ageist perceptions of clothing. Terms such as ‘frumpy’, ‘unsexy’, and ‘old-fashioned’ demonstrate a demand for hip protector garments that defy ageism and reflect more appropriately the lifestyle aspirations of these potential users.

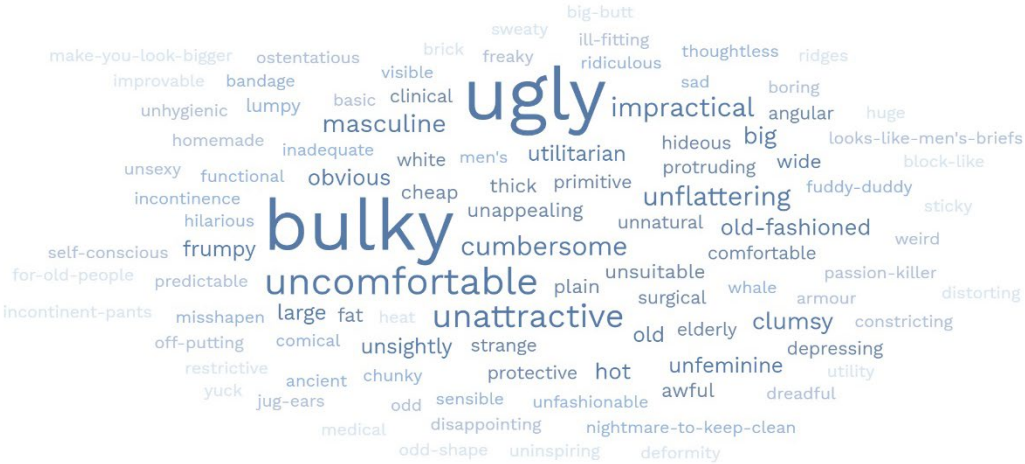
Table 9: Word clouds of responses for three words that best describe the appearance of the underwear hip protector.

Words chosen by respondents who agreed (n=8) or strongly agreed (n=1) they liked the appearance of the underwear hip protector [most commonly used words: comfortable (3) / bulky (3) / padded (2)]:

Words chosen by respondents who neither agreed or disagreed (n=27) they liked the appearance of the underwear hip protector [most commonly used words: bulky (10) / ugly (5) / uncomfortable, unattractive and big (3)]:



Words chosen by respondents who disagreed (n=55) or strongly disagreed (n=55) they liked the appearance of the underwear hip protector [most commonly used words: ugly (44) / bulky (43) / uncomfortable (17)]:



Note: the font size reflects the number of instances the word was used. However, this is only relative to the individual sample sizes and is not comparable across the three separate word clouds.

In the padded belt hip protector word clouds (see Table 10), the most used words from the 'agree and strongly agree' group could largely be interpreted as key design criteria for any hip protector product. 'Neat', 'comfortable' and 'practical' are the top three terms used, closely followed by 'wearable', 'black', 'adjustable', 'easy', 'discreet', and 'unobtrusive'. Black is a popular colour choice among some respondents (discussed later in the online survey analysis), however, the term may simply be reflective of a literal response to the question as 'white' was also used to describe the underwear hip protector. The 'neatness' of the garment aligns with other ideas relating to compactness, discretion, and unobtrusiveness. Aspects relating to the functionality, such as 'wearable' and 'adjustable' are perhaps also indicative of perceived advantages compared to the underwear hip protector.

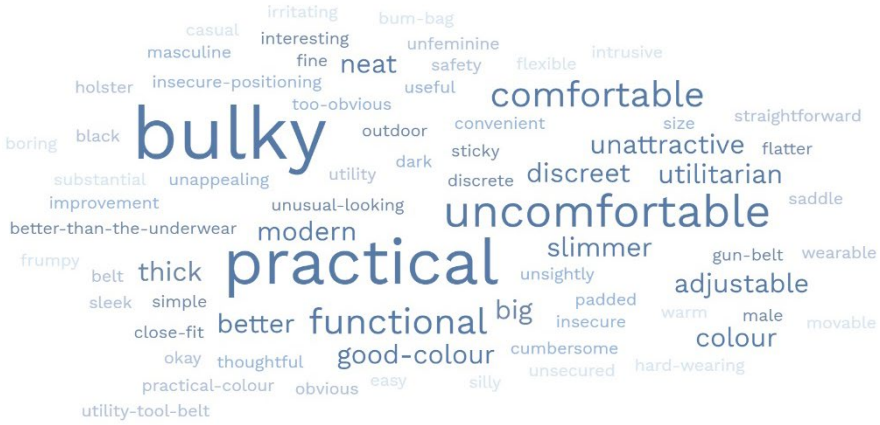
The words chosen by the padded belt hip protector 'neither agree or disagree' group seem more neutral (in keeping with this category) than the equivalent underwear hip protector group. Although the words 'bulky' and 'uncomfortable' are prominent, the second most common word is 'practical' and other positive terms are used, such as 'modern', 'adjustable' and 'discreet'. This may reflect a generally broader level of receptivity towards the appearance of this product compared to the underwear. However, the limitation here is that the responses are towards images of the garments rather than seeing the physical product. This could explain some contradictions at play, most notably the perception by some that the garment would be 'uncomfortable' and yet almost as many noting 'comfortable'. This might relate to different perceptions of how the product would be worn, or perhaps a reflection compared to the underwear hip protector. Indeed, some words, such as 'slimmer', 'better' and 'flatter', demonstrate a direct comparison to the underwear garment the respondents reviewed first.

In the 'disagree and strongly disagree' group, the same three words are most used as in the equivalent underwear hip protector group: 'bulky', 'uncomfortable' and 'ugly'. Although fewer respondents disliked the appearance compared to the underwear hip protector, concerns are shared relating to the garment seeming cumbersome and unfeminine for female users.

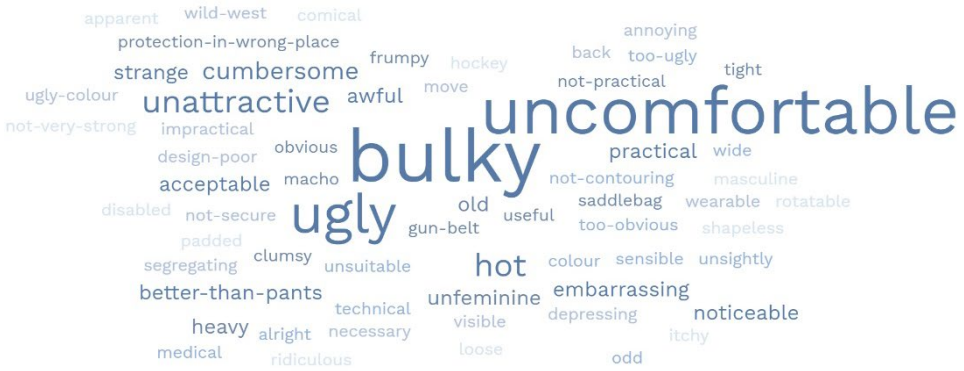
Table 10: Word clouds of responses for three words that best describe the appearance of the padded belt hip protector.

Words chosen by respondents who agreed (n=46) or strongly agreed (n=12) they liked the appearance of the padded belt hip protector [most commonly used words: neat (9) / comfortable (8) / practical (7)]:

Words chosen by respondents who neither agreed or disagreed (n=42) they liked the appearance of the padded belt hip protector [most commonly used words: bulky (7) / practical (6) / uncomfortable (4)]:



Words chosen by respondents who disagreed (n=35) or strongly disagreed (n=11) they liked the appearance of the padded belt hip protector [most commonly used words: bulky (16) / uncomfortable (14) / ugly (11)]:



Note: the font size reflects the number of instances the word was used. However, this is only relative to the individual sample sizes and is not comparable across the three separate word clouds.

With regard to Topo and Iltanen-Tahkavuori's (2010) framework of patient clothing, for many respondents the padded belt hip protector sits towards the more desirable end of normality and continuity. However, aspects relating to, “clothing that highlights and stigmatises disabilities” clearly resonates with some respondents who are put off by the ‘obvious’, ‘noticeable’ and ‘embarrassing’ qualities of a garment that is visibly worn over clothing. Similarly, terms such as ‘gun belt’, ‘saddlebag’, and ‘macho’ reflect meanings that are, “not in accordance with cultural norms of clothing” for some users.

4.3.3.2 Coding hip protector preferences

I generated codes relating to what respondents liked about the appearance of the hip protector examples (see Table 11), and changes to the appearance of the product that would make it more appealing (see Table 12). These were organised into visceral, behavioural, and reflective categories. Technically, all the responses should fit in the visceral group as the survey questions explicitly asked respondents to comment on the *appearance* of the hip protectors. In fact, 25 of the codes fall within the visceral group whereas the behavioural group has 34 and the reflective group has 10. However, the findings that have emerged from the behavioural and reflective group comments provide a broader insight into attitudes towards existing hip protectors. There is a greater variation of responses relating to the perceived functional attributes of the hip protectors, interpreted from the images, rather than their aesthetics. Although, more instances of responses using visceral codes were recorded overall, compared to behavioural or reflective.

In the small sample of respondents who liked the appearance of the underwear hip protector, the discretion of the product appears to be a key factor. One respondent noted, “It’s quite hidden and not too noticeable” and another commented that it was, “easy to conceal under a skirt”. However, most respondents thought the opposite was true, with an emphasis on the desire to ‘hide’ or ‘conceal’ the hip protector from others (liking that it is ‘discreet’, n=5, versus changing it to be ‘less obvious under clothing’, n=39).

Table 11: Visceral, behavioural, and reflective categories of codes in response to what is liked about the appearance of hip protectors.

Question	Visceral	n	Behavioural	n	Reflective	n
What do you like about the appearance of the underwear hip protector?	***Neat***	1	***Perceived protection***	2	***Discreet***	5
	Funky	1	***Perceived comfort***	2		
	Puffy	1	Perceived supportiveness	1		
	Sexy	1	Fitted	1		
Total		4		6		5
What do you like about the appearance of the padded belt hip protector?	Not too bulky	10	***Perceived comfort***	9	***Discreet***	17
	Colour	7	Can be worn over clothing	8	Less impact on body shape	4
	Prefer to appearance of underwear	7	Perceived ease of use	5	Can be hidden	1
	Like a 'bum bag'	6	Can be worn under clothing	4	Signals fall risk	1
	Neat	3	***Perceived protection***	3	Not pretending to be something else	1
	Like a belt	3	Practicality	3		
	Visible	2	Removeable	3		
	Modern	2	For walkers	2		
	Fashionable	2	Fabric/materials	1		
	Acceptable	1	Can be worn with most garments	1		
	Stylish	1	Separate to underwear	1		
			Perceived lightness	1		
			Simplicity	1		
			Convenient	1		
Total		44		43		24

Note: codes in bold italics are used to describe both types of hip protector.

Table 12: Visceral, behavioural, and reflective categories of codes in response to suggested changes to the appearance of hip protectors.

Question	Visceral	n	Behavioural	n	Reflective	n
What changes to the appearance of the underwear hip protector would make it more appealing to you?	***Less bulky pads***	68	***Change fabric/materials***	18	***Less obvious under clothing***	39
	More feminine	19	Fit under clothing	14	***Better shaped to form of body***	23
	Change the style	18	***Increase coverage/protection***	8	More appealing to younger people	1
	Change colour/pattern	13	***Improve comfort***	4	Inexpensive	1
	Like sportswear	6	Easier to use	4		
	Gender specific underwear	4	Reduce size	4		
	Sexier	2	***Use with own underwear***	3		
	Less old-fashioned	2	Remove crotch	3		
	Better integration of padding	2	Washable	2		
			Worn over clothes	2		
			Not underwear	2		
			Accommodate incontinence pads	1		
			Not to sit on waist	1		
			Adjustable	1		
Total		134		67		64
What changes to the appearance of the padded belt hip protector would make it more appealing to you?	***Less bulky pads***	20	Prevent position movement	15	More discreet	9
	Different colour options	13	***Change fabric/materials***	7	***Better shaped to form of body***	3
	Change colour/pattern	11	***Improve comfort***	5	***Less obvious under clothing***	1
	Change the style	8	***Increase coverage/protection***	4		
	Like sportswear	3	Add pockets	4		
	More feminine	2	Worn under clothes	3		
	Like a 'bum bag'	1	Not a belt	2		
			Use with own underwear	1		
Total		58		41		13

Note: codes in bold italics are used to describe both types of hip protector.

For those who liked the appearance of the padded belt hip protector, the discretion of the product was the most noted attribute. However, this tended to focus more on the ability of the padded belt to blend in with other clothing, or how it could be disguised to look like a ‘bum bag’ or similar. One respondent commented, “in fact, it could be integrated into [the] design so that people think that’s what you are wearing”. Another noted that, “it disguises itself on clothes”.

The ease and perceived comfort of wearing a hip protector over clothes was noted by some but comments also related to discretion and body image. One respondent thought that it could, “be worn over trousers so [it] might be easier to hide under loose tops”. Another preferred the external visibility of the product, reasoning that it, “looks like it can be worn on top of clothes so [it] won’t make my hips look big”. Several respondents felt that the product was not too bulky which may have been informed by their earlier impressions of the underwear hip protector.

The black colour was seen as “acceptable” and “unobtrusive” by two of the respondents but most who mentioned it simply noted that they liked the colour, without explanation. One respondent suggested that it, “could be produced in different colours to go with your clothes”, a theme that is also reflected in later responses to changes to the appearance of the padded belt hip protector.

The question relating to changes to the appearance of the underwear hip protector garnered 128 separate comments, the highest response rate of the four questions. The most common suggestion was to reduce the bulkiness of the pads, which is also reflected in the earlier word clouds. The visual bulk of the hip protector is naturally connected to the other common suggestions, to make it less obvious under clothing and better shaped to the form of the body. For example, one respondent suggested making it, “more tapered to mimic hip shape and not such an obvious 'bump'”. Some respondents were more explicit about body image with one noting that, “I would not want it to make my hips look wider, I already have wide hips”. Several respondents were also concerned about clothes not fitting over the hip protector and having to buy looser fitting garments.

Changes to the visual style of the garment were noted in many responses, including suggestions to make it more feminine (or separate styles for men and women), or more like sportswear. The ‘Change the style’ code incorporates more general responses, such as to make it less “ugly” or “boring”. A 60-69 year old woman, in the highest fall risk group, reflected a common sentiment from the survey and earlier focus groups:

> “Everything! The sponges look stupid. I'm a modern dresser and still feel young, this has all the looks and style of catapulting me into a 'totally disabled, very old person, my life is over' person!”.

Many respondents also suggested changes to the fabric or materials used in the garment. In particular, the key requirements were that it was “breathable” and “light weight”, using “natural fibres” that are “sustainable”.

Finally, 74 responses were recorded for the question relating to changes to the padded belt hip protector. As seen with the word cloud analysis, and in the criticism of the underwear hip protector, less bulky pads are a primary concern. Similarly, this links to reflective category comments related to making the product more discreet, particularly for those who would envisage wearing the padded belt hip protector under their clothing. One respondent suggested, “Something that won't obviously look like you have something bulky under your clothes”, and another simply noted, “I would prefer it not to look so noticeable”.

A significant concern, not evident in responses relating to the underwear hip protector, was that the padded belt would be susceptible to moving out of its correct position, impacting on its efficacy in the event of a fall. This point was raised by several respondents, including one who noted simply, “I’m not convinced this would stay in place”, and another who suggested adding, “some kind of rubber on the exterior so it doesn’t slip around”. There is, in fact, a silicon bead on the inside surface of the padded belt hip protector for this purpose but this was not visible in the image.

The colour of the product was also a key area suggested for development. Most respondents were keen to see “different colours” or “a choice of colours”, to correspond with other clothing, as suggested earlier, but did not specify particular colours. However, three respondents who felt they would wear the product under clothing, suggested that a range of colours to correspond to skin tone would be preferable. This reflects the approaches taken by hosiery manufacturers, such as Falke (2024), whose products accommodate a diverse choice of colours to compliment different users’ skin tone. However, no data on ethnicity was gathered through the online survey and this is an area that would require further investigation.

Overall, the coding of responses in Table 11 and Table 12 provides an indicative list of criteria that could inform the development of new designs of hip protector products. These findings reinforce the earlier observations interpreted through the word cloud analysis. Although the padded belt was more broadly accepted compared to the underwear product, it cannot be assumed that a hip protector worn over clothing is right for everybody. Indeed, the need for discretion and, for some, the product to be *hidden* is clear.

4.3.3.3 *Preferences clustered by age*

There are significantly more visceral coded comments related to changes to the appearance the underwear hip protector compared to the padded belt, reinforcing the low number of responses from people who said they liked its appearance. However, there are nearly an equal number of behavioural and reflective coded comments about changes to the underwear demonstrating an even distribution of criticism levelled at how it might perform and how an individual's self-image might be affected wearing it. This cannot be said for the padded belt hip protector where reflective comments are proportionately fewer than behavioural, indicating fewer respondents who would feel too self-conscious wearing it. Analysing the visceral, behavioural, and reflective category responses within different age groups indicates if these attitudes are generalisable across the whole sample.

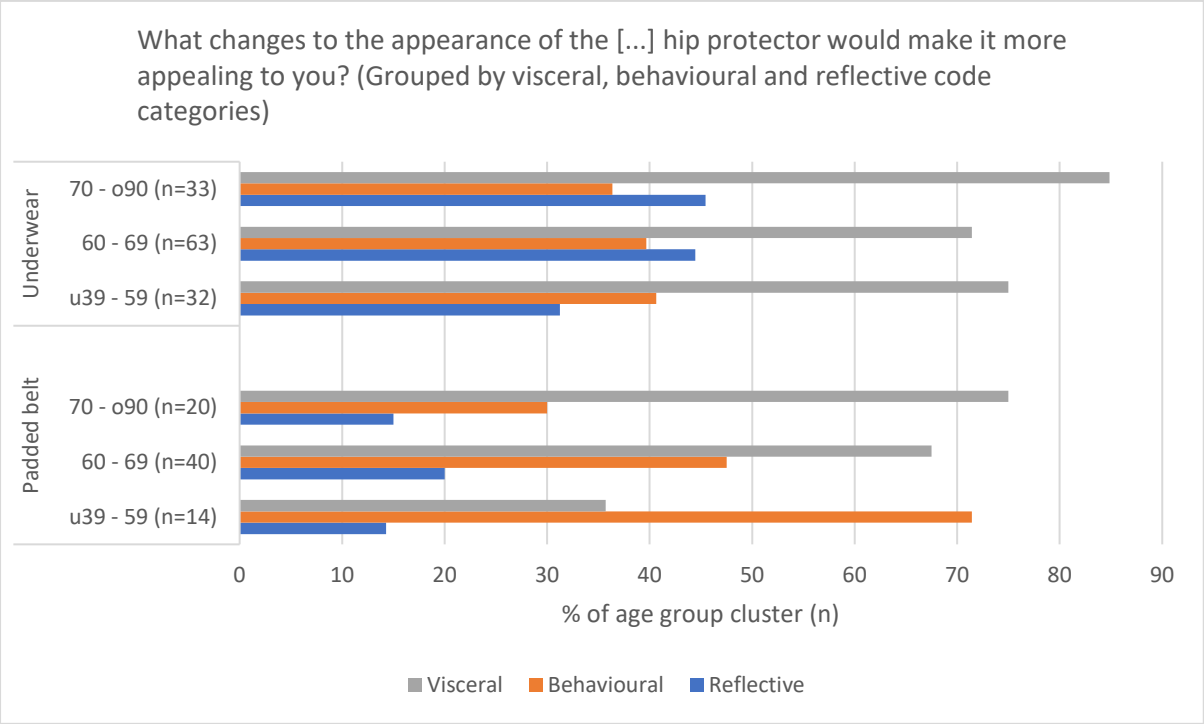


Figure 40: Comparing visceral, behavioural, and reflective categories of codes in response to suggested changes to the appearance of hip protectors clustered by age.

The number of coded responses were recorded and calculated as a percentage of each age group cluster (see Figure 40). With the underwear hip protector, visceral and reflective responses appear to become more likely with age, although the opposite is true for behavioural responses. A greater emphasis on the visual appearance of the garment, and how one appears to other people, perhaps

reflects internalised ageism and the negative ways many older women evaluate their bodies and appearance (Hurd Clarke 2010; Twigg 2013). The difference in visceral and behavioural responses across age with respect to the padded belt hip protector are even more pronounced. Again, the older respondents were more likely to be concerned with the visual appearance (visceral) of the product than the younger respondents.

The younger respondents are more greatly represented in the lower fall risk categories. One explanation for their bias towards behavioural responses could be that issues such as comfort and performance are seemingly more pressing for a group less likely to feel the need to wear a hip protector any time soon. Although this seems counterintuitive, it may be that the visual appearance is less important to them when considering a garment primarily designed for its functional capability, especially if the reality of wearing it feels somewhat abstract.

These findings are reinforced further by the responses to later questions relating to the preferences of underwear and padded belt hip protectors. A range of scenarios were provided that probed the preferences towards hip protectors worn over or under clothing (see Figure 41), of which respondents could choose any that applied to them.

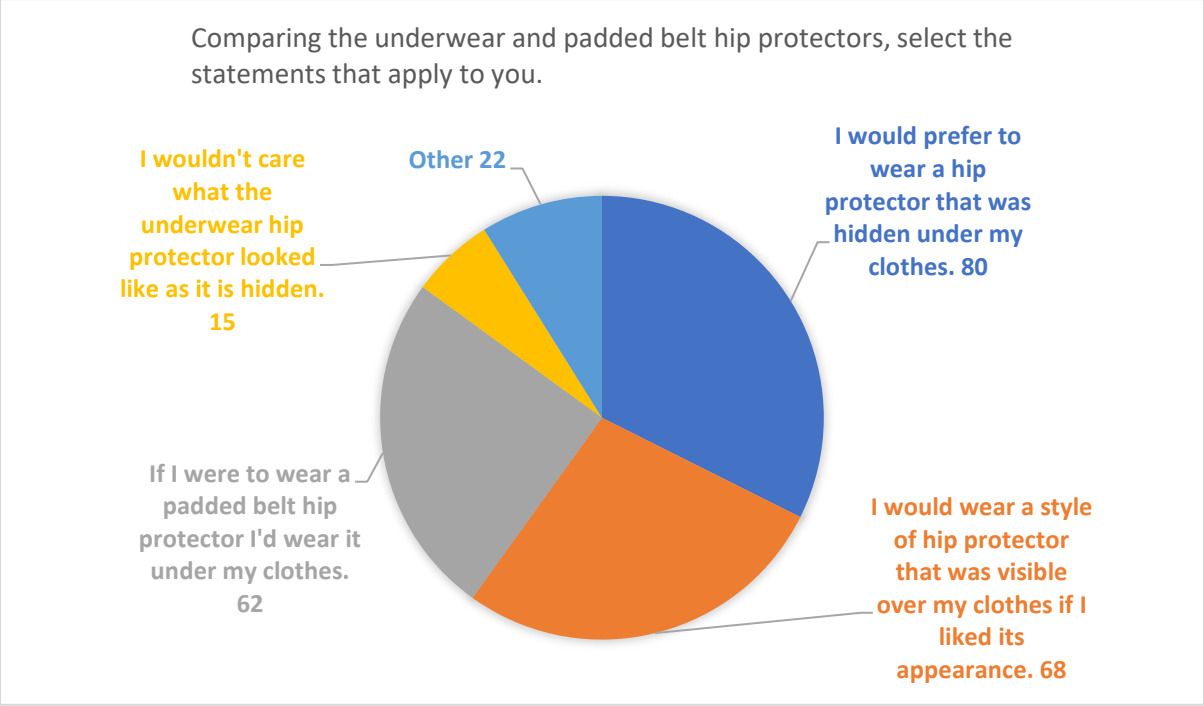


Figure 41: Responses to different scenarios reflecting preferences to how hip protectors would be worn.

It is notable that the most frequently selected statement was, 'I would prefer to wear a hip protector that was hidden under my clothes', although this is followed closely by, 'I would wear a style of hip protector that was visible over my clothes if I liked its appearance'. This shows a similar distribution between those who would prefer the product to be hidden and those who would be receptive to a visible hip protector.

However, the distribution of responses clustered by age (see Figure 42 and Figure 43) further illustrate that older respondents are more likely to prefer a hidden hip protector and less likely to want to wear one that would be visible over clothing. The same trend is seen with the statement 'If I were to wear a padded belt hip protector I'd wear it under my clothes', where the proportion of responses increases with age.

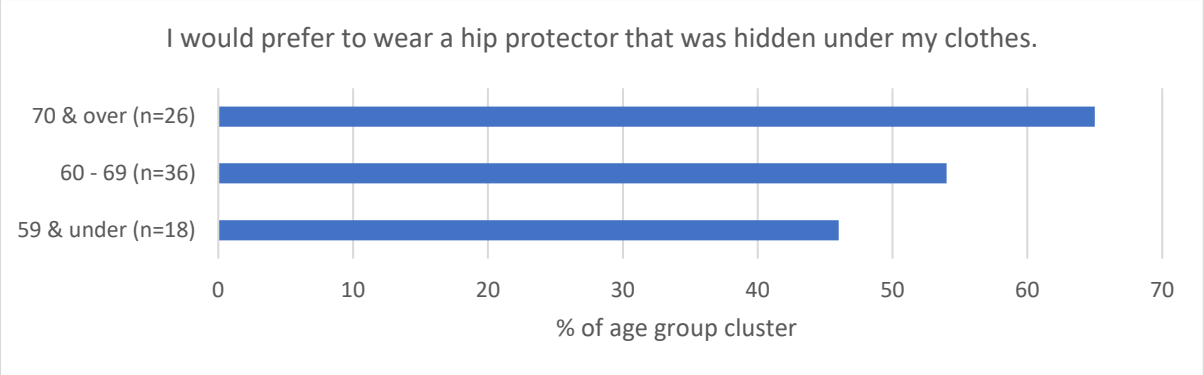


Figure 42: I would prefer to wear a hip protector that was hidden under my clothes. Responses clustered by age.

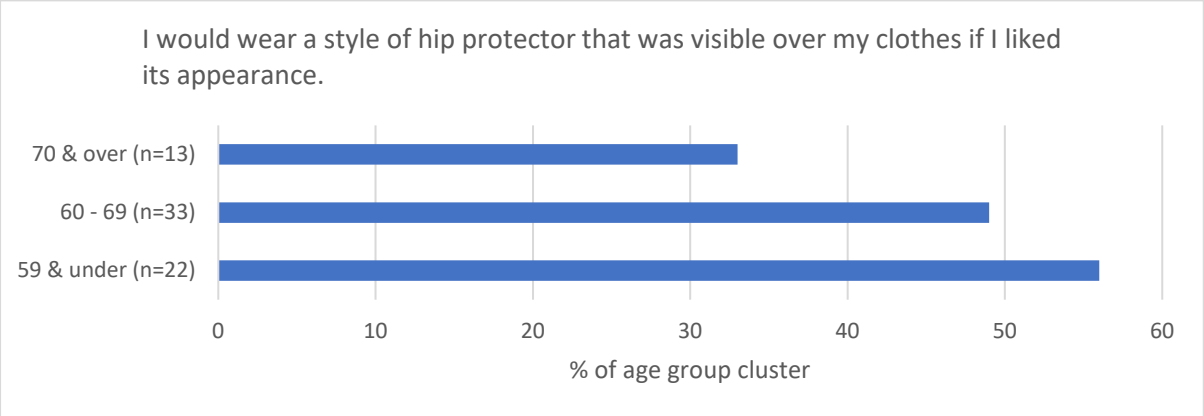


Figure 43: I would wear a style of hip protector that was visible over my clothes if I liked its appearance. Responses clustered by age.

The very low number of responses to the statement ‘I wouldn't care what the underwear hip protector looked like as it is hidden’ clearly indicates the demand for hip protectors to appeal to users across the visceral level, regardless of whether they are visible when worn or not.

22 respondents also provided an ‘other’ scenario which helped to contextualise the remaining statements they had chosen. It was noted by some that the choice of hip protector could be context dependent. Tideiksaar (1997) identifies extrinsic factors, such as hazardous environmental conditions, as a key contributor to falls, which could likely influence hip protector use. For example, a 60-69 year old woman in the highest fall risk category added, “The situation might make the difference. If I was walking for exercise, I may not mind either. However, if I was smartly dressed, I don’t think I would wear either”. Several respondents were also concerned with the efficacy of the product too, such as a 50-59 year old woman, with a lower risk of falls, who had noted she would wear a visible hip protector: “I would need to believe it could do the job and was not a gimmick to go to the trouble to wear it”.

4.3.3.4 Reflection

The survey data has provided significant insights into the attitudes and acceptance of two different types of hip protector garments. The meanings interpreted from these garments is particularly evident through the word cloud analysis, and within the feedback on their appearance distributed through visceral, behavioural, and reflective categories. These meanings are, of course, context dependent, and different scenarios of use will also have a bearing on how willing someone at risk of falls and fragility fractures would be to wear hip protectors. The scope of contexts of use will be explored in more detail in the analysis of data from part 2 of the survey.

This investigation into the preferences of hip protectors worn under (hidden) or over (visible) clothing indicates that respondents are more receptive to wearing the padded belt style and are more positive about its appearance. The reported benefits compared to the underwear hip protector include its discretion and lack of bulkiness, the perceived comfort and ease of use, and its colour. However, although greater receptivity was shown towards the appearance of the padded belt hip protector, many respondents preferred it to still be hidden and worn under clothing. As discussed earlier, this trend was particularly noticeable with older respondents and reflects the attitudes of both female and male participants who took part in the earlier focus group (see 4.2). In the development of new types of hip protectors, care must be taken to accommodate the needs of users

who value complete discretion, but also understand the audience and contexts where a hip protector worn over clothing is desirable.

From the analysis of part 1 of the online survey, the following criteria are noted as key priorities for hip protector design:

- To prioritise visceral qualities, including:
    - Neat and compact, not bulky.
    - Reflective and inclusive of different genders.
    - Range of colours.
    - Modern style that could take cues from contemporary fashion or sportswear.
    - Avoidance of visual characteristics related to hospital patient clothing.
- To prioritise behavioural qualities, including:
    - Reliable hip protection.
    - Potential to be worn under or over existing clothing.
    - Comfortable.
    - Easy to use.
    - Sustainable, natural fibres that are breathable and lightweight.
- To prioritise reflective qualities, including:
    - Discreet or hidden from view.
    - Shaped to form of the body to make it less obvious.

4.3.4 Attitudes towards inflatable hip protectors (Part 2)

The barriers to acceptance of traditional types of hip protectors are well reported in the literature (see 2.2.3). Manufacturers such as Active Protective Technologies, Helite, and S-Airbag produce inflatable hip protectors consisting of airbags that automatically deploy if the wearer starts to fall (see 2.3.5). Acceptance of wearable airbags is an under-researched area, so further investigation is needed to understand perceptions of using these products. There are three aspects to using an airbag hip protector that could be perceived as disadvantageous compared to their 'low-tech' counterparts. The potential barriers of product cost, the requirement to recharge batteries, and the requirement to replace compressed gas cartridges after the airbags are deployed, are explored through the analysis of responses below.

4.3.4.1 *Attitudes towards the cost of airbag hip protectors*

The first question asked: Would you be prepared to pay significantly more for an airbag hip protector compared to an underwear of padded belt hip protector? (See Figure 44).

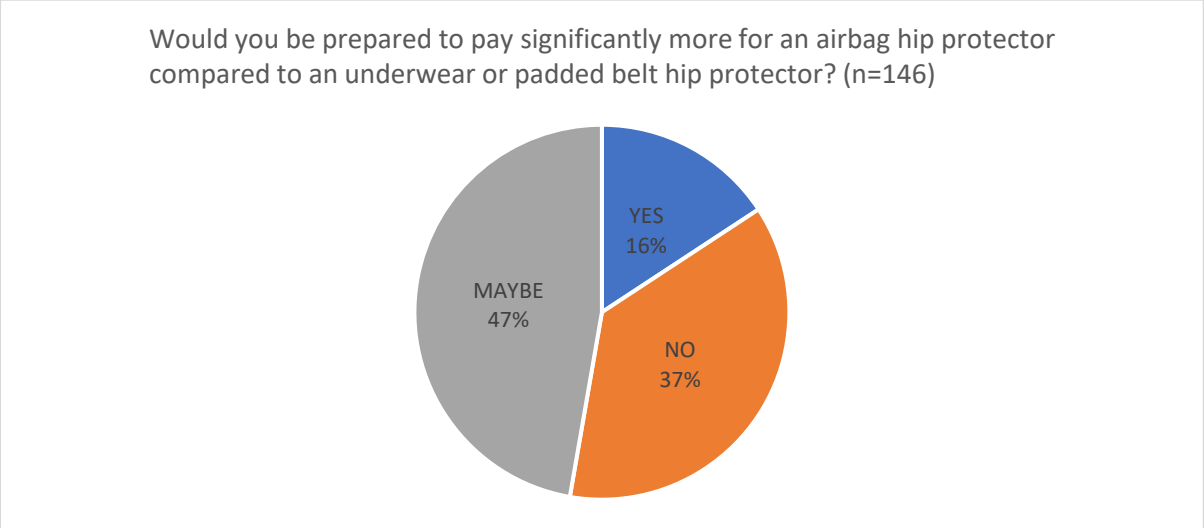


Figure 44: Proportion of responses related to being prepared to pay significantly more for an airbag hip protector.

With only 16% (n=23) of women answering 'yes', cost could be a significant barrier to acceptance. This is also reflected in the 37% (n=54) who answered 'no'. Almost half of the respondents answered 'maybe' (47%, n=69), perhaps also demonstrating that some further convincing is needed regarding cost versus benefit.

The reasons for this answer, provided through the follow-up question, were coded, and are presented in Table 13. For women who answered 'no', the most common reason was due to affordability ('too expensive', n=23). In addition to the product appearance and wanting it to be more discreet, other key reasons related to the high-tech nature of airbag hip protectors, such as concerns about maintenance and the risk of too frequent inflation.

Table 13: Attitudes towards the cost of airbag hip protectors. Coded responses to 'yes', 'no' and 'maybe' answers where codes have been applied in 3 or more instances.

Question	Yes	n	No	n	Maybe	n
Would you be prepared to pay significantly more for an airbag hip protector compared to an underwear or padded belt hip protector?	Less obtrusive	11	**Too expensive**	23	**Depends on cost**	16
	Worth it to prevent fracture	9	Improve appearance	6	Depends on effectiveness	15
	Only there when needed	4	Maintenance concerns	5	Depends on fall/fracture risk	13
			Inflate too regularly	3	Make discreet/hidden	10
			Make discreet/hidden	3	Like the concept	7
			Too extreme	3	Improve appearance	6
					Maintenance concerns	6
					If less bulky	4
					Need to know cost vs benefit	3
					Risk of inflating accidently	3
					Safety concerns	3

Note: codes in **bold** are also applied to other questions.

Respondents who were not prepared to pay significantly more for an airbag hip protector tended to be older, with 42% (n=28) of 60-69 year olds and 40% (n=16) of those 70 and older (see Figure 45). Only 26% (n=10) of those 59 and under responded with ‘no’ but this group had higher representation in the ‘maybe’ group. Lower acceptance in older populations is a concern as they are more likely to be at risk from falls. In some instances, however, the respondents’ risk of frequent falls was the actual reason they would not want to purchase an airbag hip protector. One woman noted, “I’m quite unstable and fear the airbags would inflate too regularly” and another described inflation happening “possibly very frequently”.

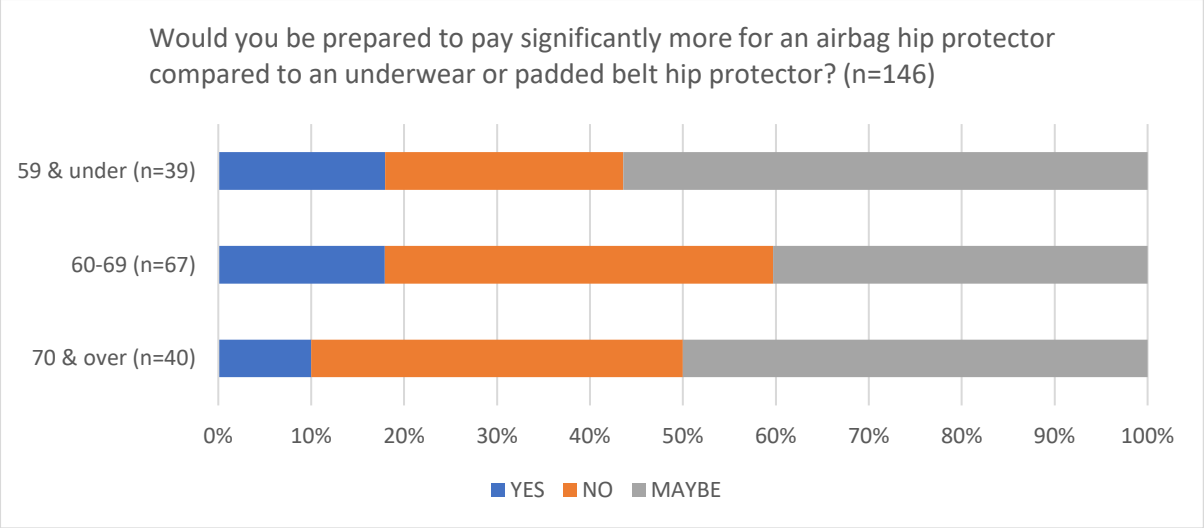


Figure 45: Proportion of responses related to being prepared to pay significantly more for an airbag hip protector, clustered by age.

The largest number of coded responses is in the 'maybe' group. Notably, the most frequent response 'depends on cost' (n=16) again indicates that the expense of the product could be prohibitive for some. However, the code 'depends on effectiveness' (n=15) is used almost as many times indicating those respondents would need to be certain of the efficacy of an airbag hip protector before committing to the cost (note the 'need to know cost vs benefit' code). The 'depends on fall/fracture risk' code (n=13) was also used frequently by respondents who would be more inclined to pay more as their risk of falls increased with age. This contrasts with earlier concerns, from respondents who experience frequent falls, about the product inflating too often. Airbag hip protectors may require a 'Goldilocks' moment of perceived falls risk to be most effective.

There were also reliability and safety concerns relating to the technology, and a perception that wearing batteries and compressed gas on your body could be dangerous. One respondent asked, "aren't gas cylinders flammable?", and another commented, "I am not sure that wearing something that contained batteries and a gas canister would be any more appealing".

Finally, within this category the same concerns relating to aesthetics are represented (reflecting earlier findings in the survey) with several iterations of the codes 'make discreet/hidden' (n=10), 'improve appearance' (n=6), and 'if less bulky' (n=4).

Ironically, 'less obtrusive' (n=11) is the most common code used when respondents would be prepared to pay more. Some of the women felt that airbag hip protectors would be more discreet than traditional hip protector garments. For example, one respondent noted, "happy to pay more if it is easier to disguise the look of the protector for everyday use", and another thought it looked, "less

obvious than the padded items, so therefore more discreet". This point reveals a limitation in the survey approach as it is impossible to know which airbag hip protector they were referring too (although with the exception of the Wolk Cloud, all other available products were visually very similar). However, regardless of the specific manufacturer, it is important to note that discretion appears to be prioritised above the product's ability to reduce the risk of hip fracture ('worth it to prevent fracture', n=9). The final significant code from the 'yes' group, 'only there when needed' (n=4) also relates to the preference for less obtrusive hip protectors. As one respondent perceived it, "invisible until required".

4.3.4.2 Attitudes towards having to keep the battery charged

The second question asked: Would you be put off using an airbag hip protector because you always have to make sure the battery is charged? (See Figure 46). In five cases the negative answer provided was inconsistent with their reasoning given later. In all these instances, the respondents had already stated that they would not buy an airbag hip protector in the first question (answering 'no') and either misinterpreted how to answer this next question or answered 'no' because they felt this question was now irrelevant to them. To protect the integrity of the data, these five responses have been removed from the analysis.

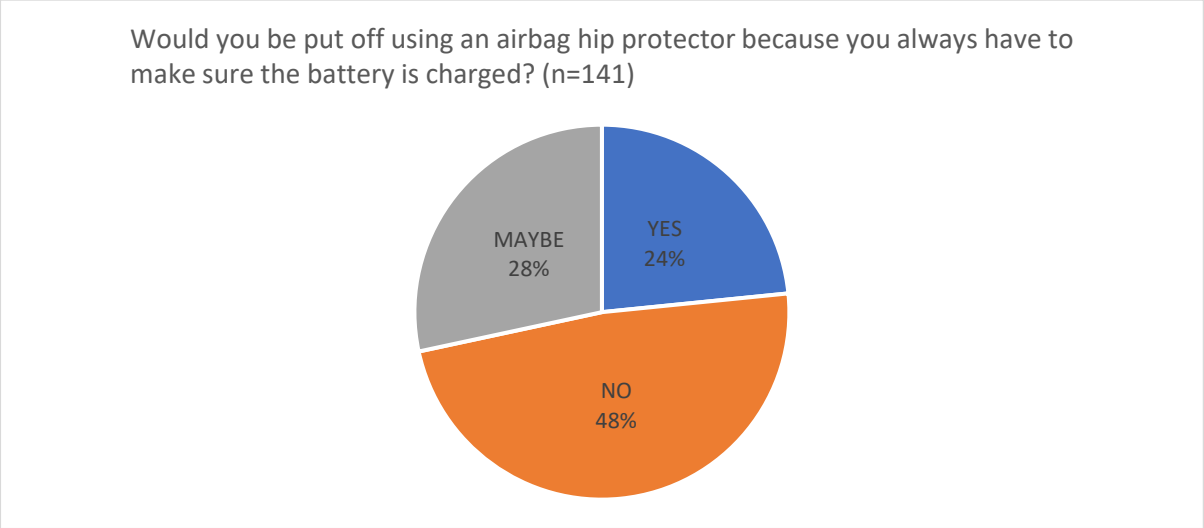


Figure 46: Proportion of responses related to being put off using an airbag hip protector because of battery recharging.

Almost half of the women (48%, n=68) would not be put off using an airbag hip protector because of having to recharge the battery. This aspect of airbag hip protectors is clearly less of a barrier to their use than product cost (although none of the respondents queried the ongoing energy costs for recharging the battery).

Table 14: Attitudes towards having to keep the battery charged. Coded responses to 'yes', 'no' and 'maybe' answers where codes have been applied in 3 or more instances

Question	Yes	n	No	n	Maybe	n
Would you be put off using an airbag hip protector because you always have to make sure the battery is charged?	Having to remember	14	Recharging devices is usual	37	Having to remember	10
	Inconvenient	6	**Worth it to prevent fracture**	9	Depends on battery life	9
	Already have enough devices to charge	4	Responsibility for using product	3	**Inconvenient**	7
					Recharging devices is usual	3

Note: codes in **bold** are also applied to other questions.

As with the first question, the same method was used to analyse the qualitative responses that rationalised the answers (see Table 14). For those who responded ‘yes’, and take issue with battery recharging, the most common reason was the pressure of ‘having to remember’ (n=14). A higher proportion of respondents aged 70 and over were put off by the battery, compared with younger women (see Figure 47). Inconvenience was also a key factor alongside the attitude that respondents ‘already have enough devices to charge’. One respondent commented, “It’s just something else to check! Glasses and hearing aids are enough”.

Reflecting on earlier concerns about wearable technology, a respondent expressed how the product felt too much like an assistive living device. She noted, “I’d prefer not to have to charge and wear batteries. That would somehow feel more medicalised and increase my sense of disability”. This resonates with the concerns of patient-scripted clothing found with traditional hip protectors.

For some women, the ubiquity of rechargeable electronic devices is a reason to not want to have to deal with another. However, for others, it is the commonplace nature of these devices that means the prospect of regularly recharging the battery of an airbag hip protector is not at all daunting. Of the 48% (n=68) of respondents who would not be put off, the code ‘recharging devices is usual’ was reflected in a significant majority of the responses (n=37).

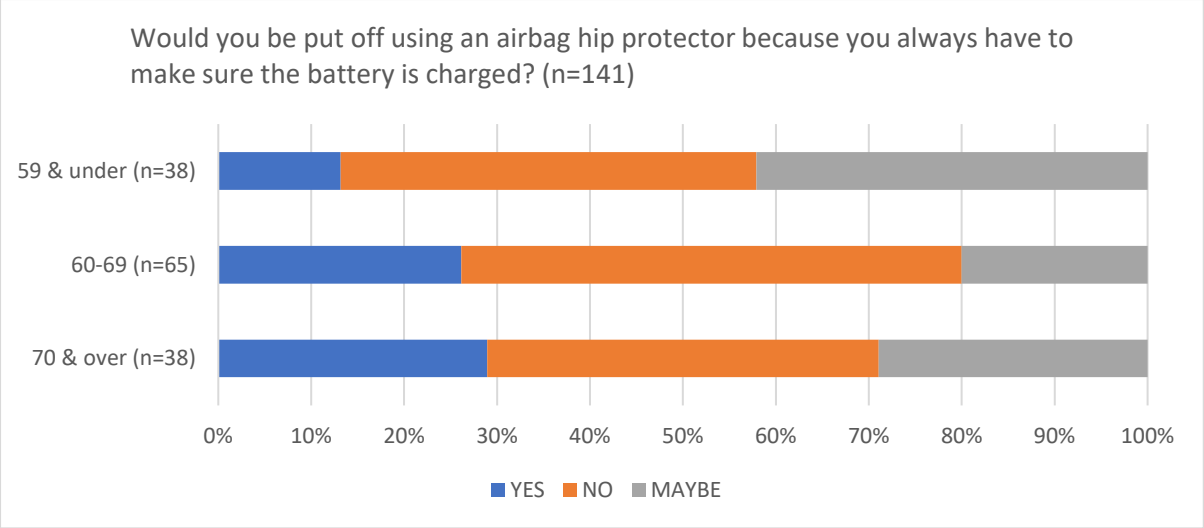


Figure 47: Proportion of responses related to being put off using an airbag hip protector because of battery recharging, clustered by age.

For several of the respondents, having to recharge the battery was a small price to pay if it helped prevent a fractured hip. 'Worth it to prevent a fracture' (n=9) was the second most common code used in the 'no' category. For example, one woman noted, "I would do whatever was needed to make sure it was effective" and another felt, "I would be more protected and confident I was safer".

28% (n=40) of the respondents, who answered 'maybe', were undecided if battery charging would be a barrier to using an airbag hip protector. The frequency of the codes 'having to remember' (n=10) and 'inconvenient' (n=7), reflects the attitudes also found in the 'yes' group. This group – most proportionately represented by the 59 and under ages – need convincing that the product wouldn't be too much hassle to own and use. The issue of battery life was also commonly reported with concerns that the device would need recharging too frequently. One respondent also commented, "I don't like the idea of a battery "running out" at an inopportune moment".

4.3.4.3 Attitudes towards having to replace the compressed gas cartridges

The final question asked: Would you be put off using an airbag hip protector because you need to replace the compressed gas cartridges every time the airbag is activated? (See Figure 48). As with the previous question, a small number of the answers were inconsistent with the reasoning provided. For this question, six 'no' responses are omitted from the data analysis due to inconsistencies.

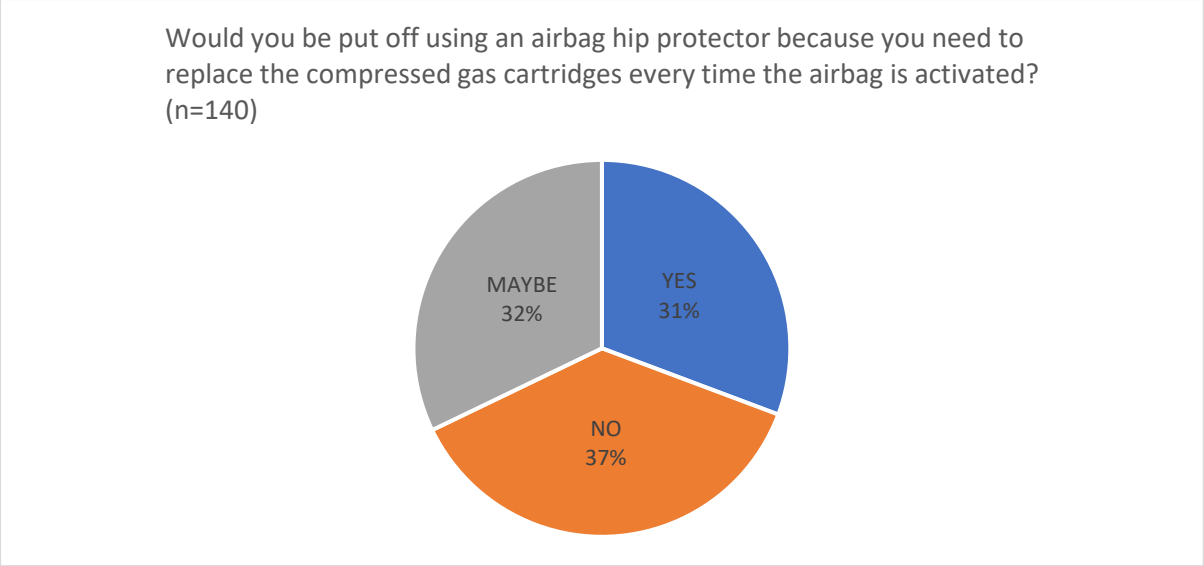


Figure 48: Proportion of responses related to being put off using an airbag hip protector due to the need to replace the compressed gas cartridges.

Compared to earlier questions, there is a much more even distribution of responses, although the slim majority (37%, n=52) seem unperturbed by replacing gas cartridges. However, 31% (n=43) of respondents would be put off using an airbag hip protector because of having to replace the gas cartridge after activation. This aspect of the product maintenance appears to be a greater barrier to acceptance than battery recharging, although both activities become less accepted with age. 38% (n=15) of respondents aged 70 and over answered 'yes', compared to 26% (n=10) of those aged 59 and under (see Figure 49).

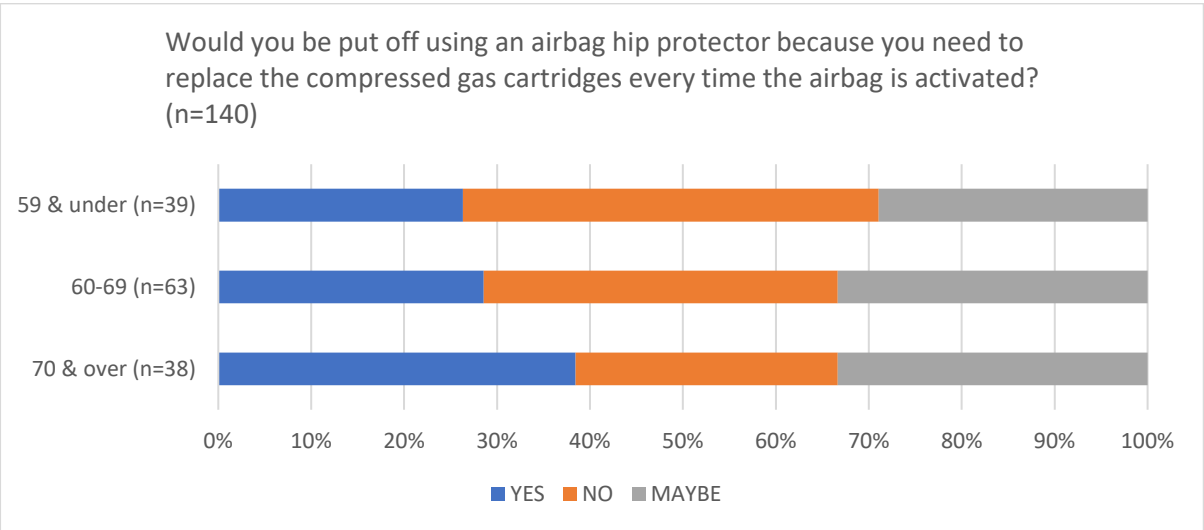


Figure 49: Proportion of responses related to being put off using an airbag hip protector due to the need to replace the compressed gas cartridges, clustered by age.

The coded responses (see Table 15) demonstrate that the key barriers, in this instance, are the perceived cost of compressed gas cartridges ('too expensive', n=16)) and the inconvenience of having to replace them ('inconvenient', n=15). Cost and convenience are two themes that appear in response to all three questions. As one respondent put it, "[It] seems a faff to have to change the cartridges; are they easy to change? Are they expensive to replace? […] In a care home setting this may be ok but for those living at home without support it could be more difficult".

Table 15: Attitudes towards having to replace the compressed gas cartridges. Coded responses to 'yes', 'no' and 'maybe' answers where codes have been applied in 3 or more instances.

Question	Yes	n	No	n	Maybe	n
Would you be put off using an airbag hip protector because you need to replace the compressed gas cartridges every time the airbag is activated?	**Too expensive**	16	**Worth it to prevent fracture**	18	**Depends on cost**	21
	Inconvenient	15	Usual maintenance acceptable	7	Depends on difficulty	10
	Too fiddly/ dexterity issues	4	Depends on frequency	5	Depends on availability	5
	Depends on availability	3	Depends on difficulty	4	Depends on frequency	4
			Depends on availability	3	**Inconvenient**	3
			Low fall risk	3		

Note: codes in **bold** are also applied to other questions.

The need for support and concern about maintaining the product independently is also reflected in comments coded with 'too fiddly/dexterity issues' (n=4). Some respondents were worried that replacing the gas cartridges would be challenging with conditions that affect hand strength and dexterity. One woman commented that it would be, "too fiddly with rheumatoid arthritis in my hands", and another noted how her fine motor control was in decline.

As with attitudes towards having to keep the battery charged, many respondents felt that replacing the gas cartridges was worth the trouble to avoid injury. 'Worth it to prevent fracture' (n=18) was the highest occurring code applied to responses from the women who answered 'no'. Similarly, this is a theme that has appeared across all three questions about airbag hip protectors. With 'usual maintenance acceptable' (n=7) some of the respondents made comparisons to household appliances where regular maintenance and replacement of consumable items was the norm.

Although the ‘no’ responses were highest, this question provoked significantly more caveats in the explanations for the answers. ‘Depends on frequency’ (n=5) relates to how often a fall might occur and the cartridge would need replacing; ‘depends on difficulty’ (n=4) is how difficult it is to replace the cartridge; and ‘depends on availability’ (n=3) relates to how easy it is to get hold of the cartridges. These codes also relate to concerns made by the ‘maybe’ group. ‘Low fall risk’ (n=3) relates to responses where the perceived risk of falling is low enough to not be concerned with the issues described above.

Finally, the most frequent code applied to the ‘maybe’ group is ‘depends on cost’ (n=21). Cost is an issue that is clearly communicated again, demonstrating that it is not only the expense of buying an airbag hip protector that could be a barrier to acceptance, but also the ongoing running costs.

4.3.4.4 Reflection

The survey findings show that the cost of airbag hip protectors and necessary on-going maintenance, such as battery charging and gas cartridge replacement, are barriers to their acceptance for some potential users. The data also provides insight into the range of attitudes – positive and negative – towards these products. However, there are some limitations to the survey design. Although an illustration showing the principle of airbag hip protectors was provided, the respondents were not asked to review one specific product. This means that feedback on the product appearance and understanding of how batteries are charged, and gas cartridges replaced, will vary between respondents. The findings, therefore, are an indicative review of attitudes towards airbag hip protectors, providing a useful perspective on the perceptions of their use.

The inconsistent answers to the second and third question suggest an issue with the question format. For the first question, some respondents clearly articulated that they would not be interested in using an airbag hip protector, which impacted on their later answers. The issue could be solved by adding a branching question at the beginning to establish which respondents are receptive to the concept in principle.

For some women, the perceived barriers to using airbag hip protectors are worth accepting for the increased protection they provide. As one respondent put it, “I want to do all I can to avoid having a hip fracture”. Inflatable surfaces are lightweight and have excellent force attenuation properties, so their application is highly justified. However, several barriers related to this high-tech solution have emerged, such as cost, inconvenience, and safety concerns. Difficulty of use and maintenance for

older users, who may experience hand strength and dexterity issues, have also been discussed. Many of these factors suggest that airbag hip protectors would be better suited to care home environments, where ongoing product maintenance can be carefully managed, alongside protecting the most vulnerable adults from injuries from falls.

Within the community-based population, the barriers to acceptance could be overcome by capitalising on inflatable surfaces for impact absorption but perhaps where they are integrated and permanently inflated in garments. In this respect, another respondent noted, “I feel it should be a passive system such as padding. Having an active system is more complicated and could fail to operate”.

Some of the concerns relating to traditional hip protector garments, such as bulkiness and the need for discretion, are also directed towards the airbag products. One woman observed that, “the idea that the pads are not visible unless a fall occurs is appealing but the tyre effect round the waist is not”. Another respondent felt the same way, noting, “I'm not very vain but this looks like a roll around the waist; not an attractive look”. To overcome this, new hip protector designs with ‘inflatable padding’ would need to have a low profile to avoid a bulky aesthetic.

From the analysis of part 2 of the online survey, the design of new types of hip protectors could be informed by the following criteria:

- Hip protectors must be as affordable as possible to be accessible to as many people as possible.
- Hip protectors must be easy to use, especially for people with reduced mobility and/or hand strength and dexterity issues.
- Lightweight inflatable surfaces with good force attenuation properties could be integrated into a passive system to negate cost, inconvenience, and safety concerns of airbag hip protectors.
- Hip protectors should be discreet and not bulky.

4.3.5 Re-thinking hip protection (Part 3)

The final section of the survey explored lifestyle, with questions about the likely scenarios for hip protector use, preferences for clothing styles, and how these might relate to the design of hip

protectors. Another question gauged the priorities respondents placed on certain criteria for hip protector design.

The responses have helped to shape an understanding of the contexts where hip protectors might be used and inform new ideas for the visual language of hip protectors, especially those that are visible when worn.

4.3.5.1 Scenarios of use

A range of potential scenarios where hip protectors might be worn were derived through earlier discussions with focus group participants. These scenarios formed a closed-ended survey question where respondents were asked when they would most likely wear a hip protector. They could choose any that applied but could also use an 'Other' box to describe a different scenario. Across the 146 responses from women, the three most common scenarios were: whilst exercising (n=77); when going shopping (n=76); and when gardening (n=70). 34 women provided an ‘other’ scenario with the most common relating to: activities such as walking (n=12) and snow sports (n=4); environmental factors such as wet or icy conditions (n=4); or occasions when they simply felt more at risk (n=2). It is worth noting that only five women had ever worn hip protectors before (and four of these were related to sports or motorcycling), so most answers were based on using them in the future.

As with the attitudes towards existing hip protectors, we also see different trends between younger and older respondents (see Figure 50). The women aged 60-69 (n=67) report a broadly consistent number of responses across the three most common scenarios. However, of the women aged 59 and under (n=39), 59% (n=23) selected ‘whilst exercising’ compared to 41% (n=16) ‘when I go shopping’. The opposite trend is found for women aged over 69. It is perhaps unsurprising to see a higher proportion of younger women prioritise hip protection when taking part in physical exercise where perceptions of fall risk may be higher than when going shopping. However, the health benefits of exercise in older age are well reported by the World Health Organisation (World Health Organisation 2010) and is clearly understood by those such as the participants of the iCareiMove fitness classes. A rationale for hip protection designed specifically with exercise in mind is therefore evident across all age ranges.

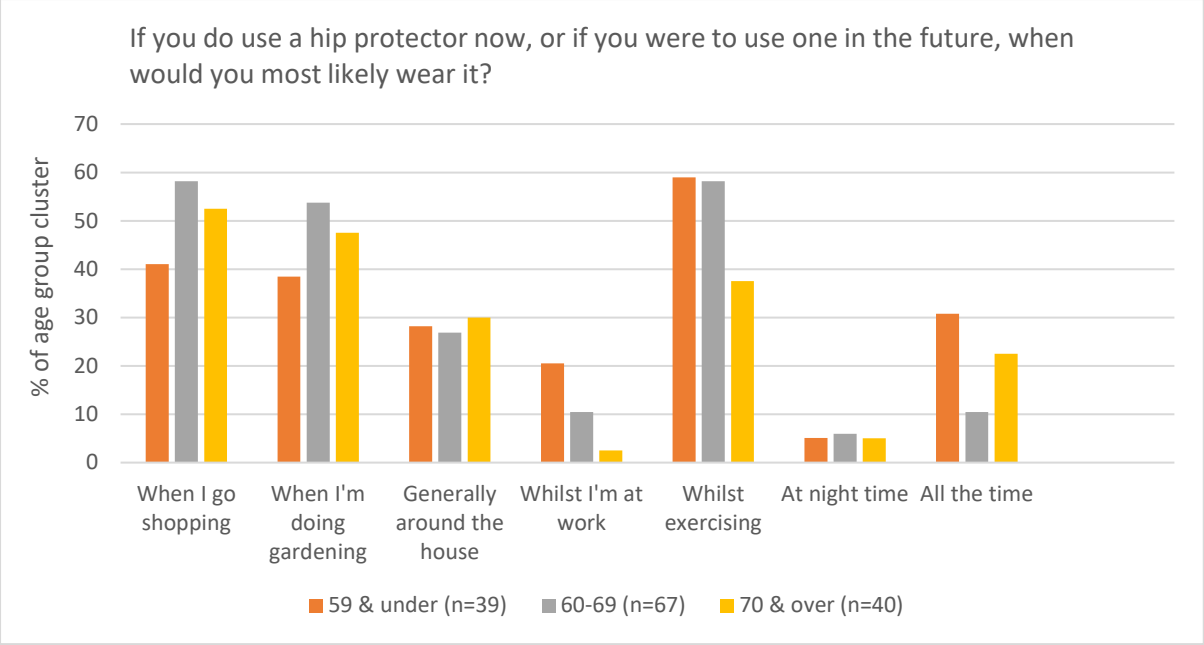


Figure 50: A comparison of different scenarios where hip protectors would be worn by women, clustered by age.

A higher proportion of younger women said they would wear hip protectors whilst at work which is unsurprising given the current UK retirement age of 66 (Gov.uk 2022). However, this is set to incrementally increase, and workers aged 65 and older will make up nearly two-thirds of employment growth by 2060 (Hill 2019). The requirement for hip protection at work, especially in manual roles such as retail and hospitality, should not be underestimated.

There is a very low response to wearing a hip protector 'at night time' across all the participants, perhaps accounting for a perceived low risk of falls when getting out of bed, for example, to use the toilet. Even for women at the highest risk of falls (n=72), only 7% (n=5) would choose to do so. However, 19% (n=28) of all aged women noted they would wear a hip protector 'all the time'. Curiously, this is slightly biased towards younger women and those at the lowest fall risk, with 75% (n=6) of the 'not true at all' fall risk group choosing this option. This perhaps relates to earlier findings that younger respondents are less concerned with the visual appearance of hip protectors when considering a garment primarily designed for its functional capability. Wearing a hip protector might feel like such an abstract idea for this group that being overly concerned about the look of the garment, or issues such as inconvenience or discomfort associated with wearing it 'all the time' are overlooked. Conversely, of the women who had already experienced a fractured hip (n=12), 42% (n=5) also noted they would wear a hip protector 'all the time'. It is highly likely that their motivation to do so is prompted by their lived experience and not wanting to repeat the trauma of this injury.

The findings demonstrate a range of likely scenarios where hip protectors might be worn. Wearing a hip protector all the time will certainly reduce the risk of injury to the user. However, these scenarios demonstrate that a one-size-fits-all approach is not appropriate, and to provide maximum opportunities for protection, different styles of hip protectors should be designed for different contexts.

4.3.5.2 Style preferences

As described in the methodology, to increase the overall sample size of women, the data from the ROS survey (women, n=146) was combined with the data from the pilot survey (women, n=25) to analyse style preferences. Respondents were asked to describe their preferred clothing style for a hip protector worn visibly over their clothes or integrated into outer garment layers. This was to understand common style choices that effect the wearers' outer appearance, and whether age and context impact on this. Although 55% (n=85) of all respondents had noted earlier they 'would prefer to wear a hip protector that was hidden under their clothes', the question still garnered some rich data which could equally apply to these garments worn under clothing.

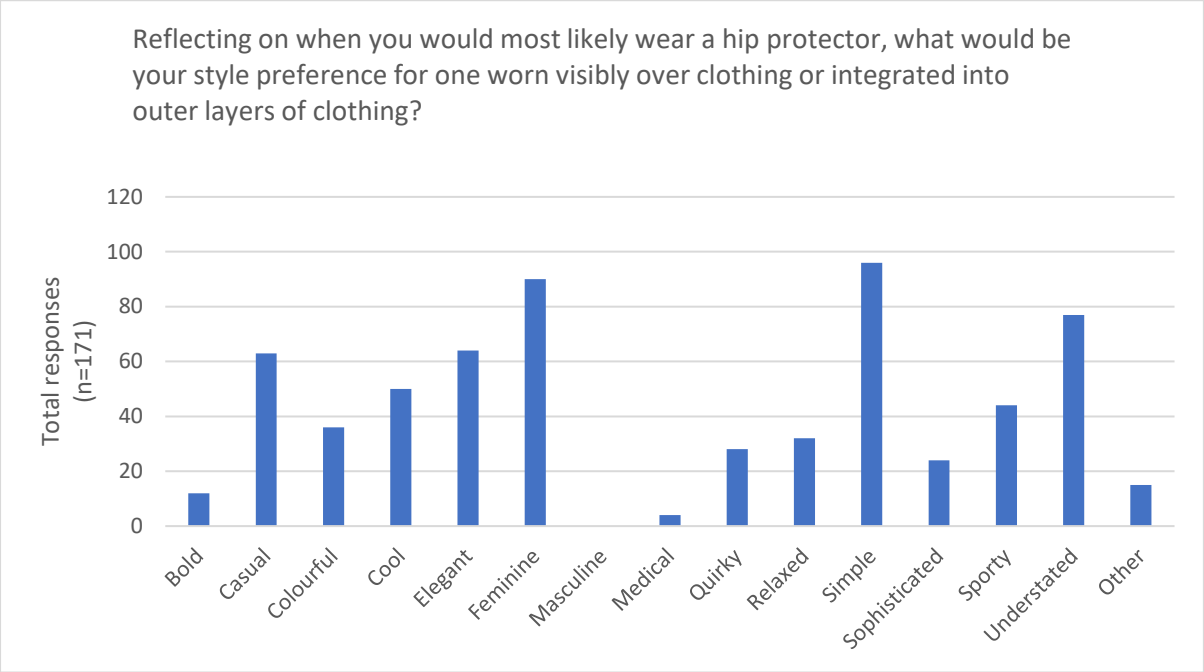


Figure 51: Distribution of style preferences of hip protectors across women from the ROS survey and pilot survey.

The closed-ended question offered a choice of styles derived mostly from web-based fashion sources such as Schuessler (2020) (see Figure 51). Overall, 'simple', 'feminine', and 'understated' were the most common words chosen, clearly reflecting the preferences towards ease-of-use, femininity and discretion observed in the critique of existing hip protectors earlier in the survey. As expected, 'medical' was not a popular style and, unsurprisingly, 'masculine' was not chosen at all. The 'Other' responses mostly related to preferences for discreet styles or completely hidden.

To cluster responses by age (see Figure 52), the data for aged under 39 (n=7) was omitted, partly because this represents such a small proportion of the sample but also because the style preferences of a very young demographic is likely to be different to mid-life and older generations. This also conveniently allows the younger (aged 40-59, n=46), and oldest group (70 and older, n=46) to be equally comparable in size. 'Simple', 'feminine' and 'understated' again feature most prominently across all three age clusters. However, there is a clear distinction between younger and older groups towards preferences for casual or sophisticated styles. Younger women seem more inclined to value a look that is sophisticated and elegant (both terms are proportionately higher with this cluster), whereas older women show a greater preference to casual styles. This defies the stereotype of clothing becoming more austere with age and reflects the observations made by Fanny Karst (see 4.1.3 Interview with a fashion designer) and Twigg (2013) about the rise of casual dress as a diffusion of sportswear in older populations.

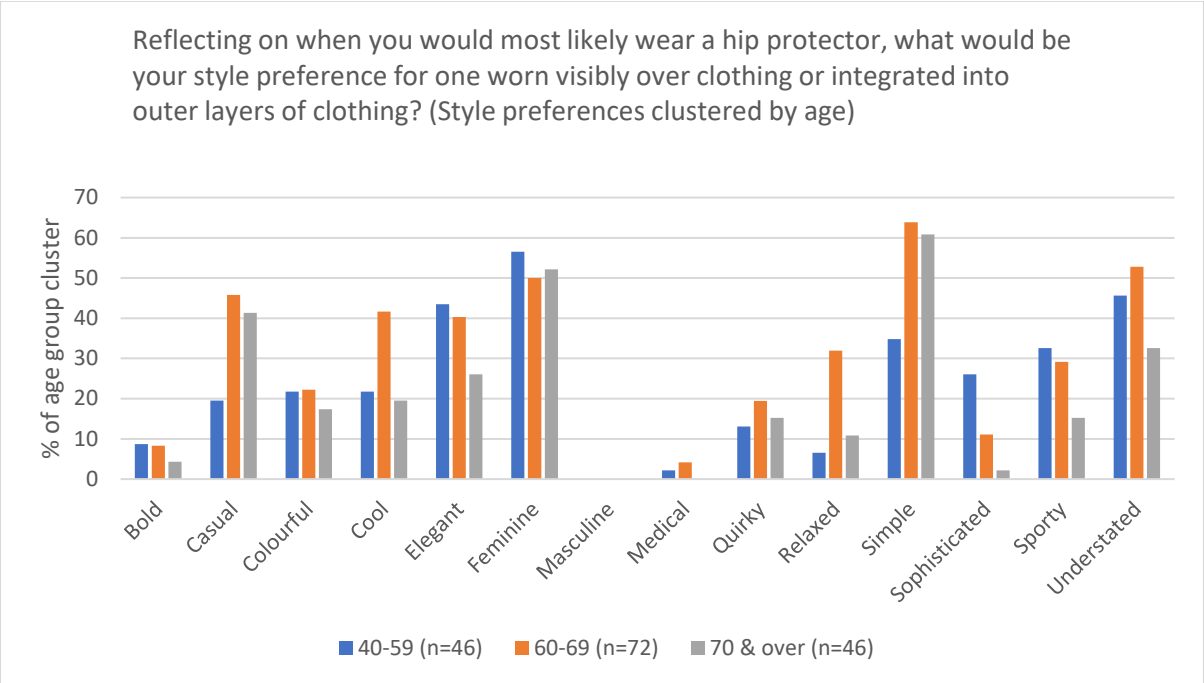


Figure 52: Distribution of style preferences of hip protectors for women clustered by age (ROS and pilot survey data combined)

A preference for 'sporty' styles is more commonly chosen by younger respondents. This reflects the context of wearing hip protectors when exercising, seen more frequently in this group. This style preference appears to be influenced by the scenario of use (see Figure 53). Although the cluster for women who would wear hip protectors at work is comparatively small (n=17), we also see greater preferences for sophisticated, elegant and colourful styles, and less interest in casual. Otherwise, the styles are fairly evenly distributed across the groups regardless of the activity.

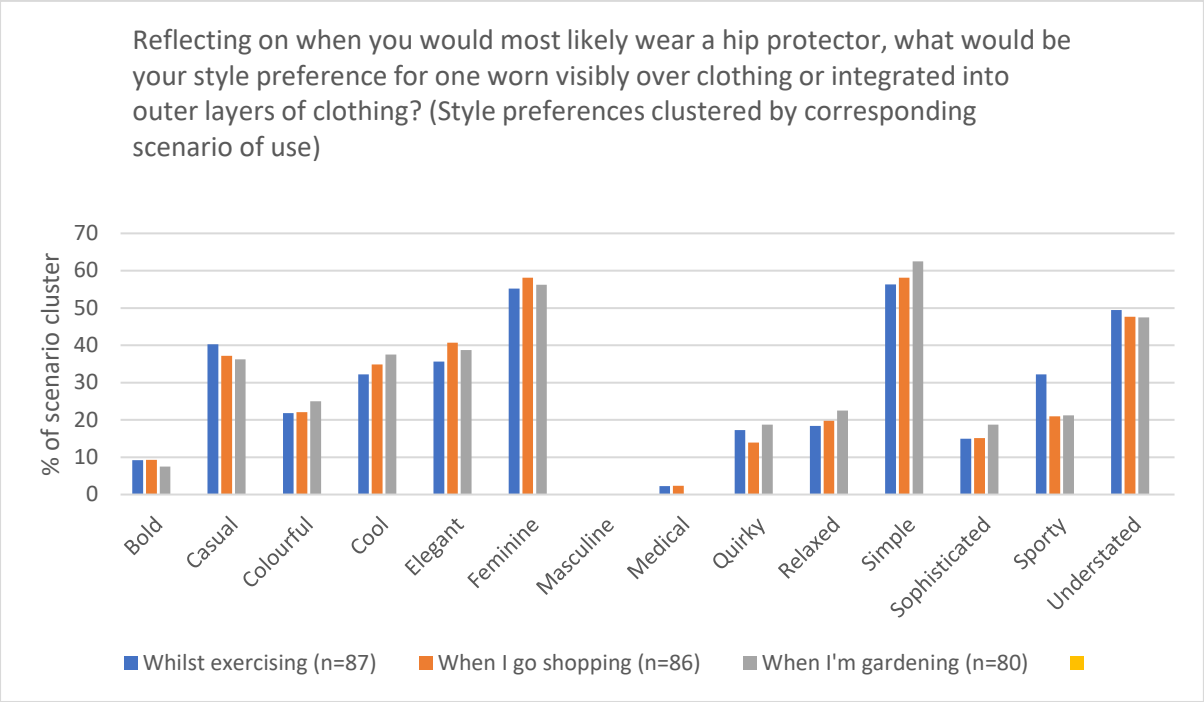


Figure 53: Distribution of style preferences of hip protectors for women clustered by scenario of use (ROS and pilot survey data combined)

Although there are a broad range of preferences of hip protector style, the findings indicate that exercising and working may be two specific scenarios where a distinctly different garment design is needed. A preference for use at night time is low but it is safe to assume that garments styled to look like nightwear would be appropriate in that scenario (although none of the respondents mentioned this). Younger women are more likely to wear hip protectors at work so perhaps this also accounts for the greater preference for sophistication and elegance – reflected in formal work wear – in the 40-59 age cluster.

4.3.5.3 *Prioritising design criteria*

The survey also explored how certain design criteria for hip protectors might be prioritised. Four criteria were presented, and respondents were asked to place them in order from most important (1st choice) to least important (4th choice) (see Figure 54). Across all ages (n=146), comfort and ease of use were ranked as the first and second choices in order of priority for most of the women. 43% (n=63) chose 'It's comfortable to wear' as their highest priority and 31% (n=45) felt that 'It's easy to put on or take off', was the most important. In this analysis, criteria concerning the performance of the garment – or *behavioural* level of design – are generally deemed the most important.

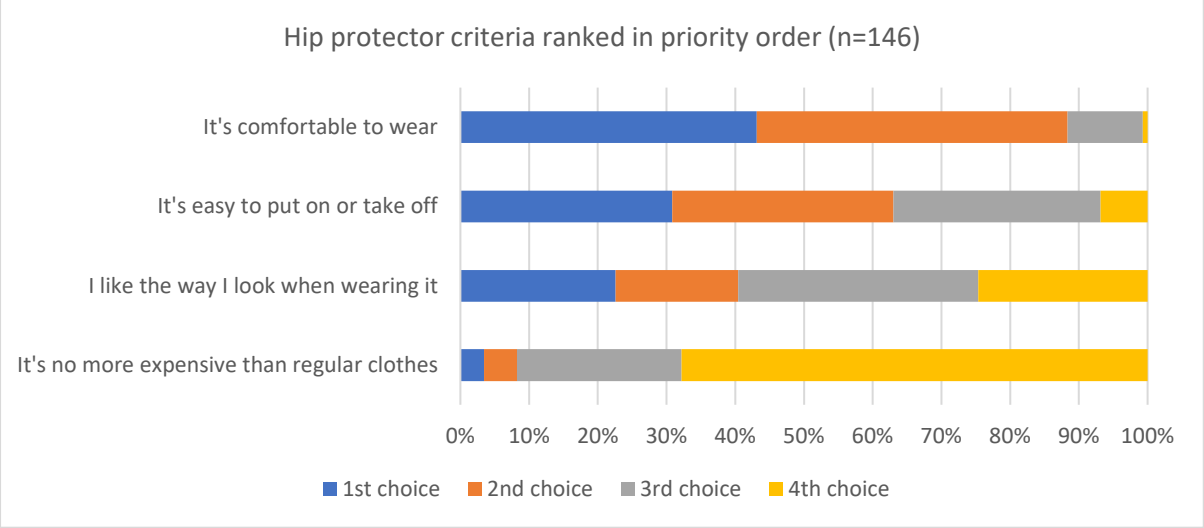


Figure 54: Criteria for hip protector ranked in priority order by all women in the survey.

35% (n=51) of the respondents chose 'I like the way I look when wearing it' as their third choice which was the most common ranking for this criterion. This criterion responds to both the *visceral* (what the garment looks like) and *reflective* (what one looks like wearing the garment) levels of design. It is worth noting that nearly a quarter of the women (23%, n=33) chose this as a priority.

The criterion 'it's no more expensive than regular clothes' was the least important for 68% (n=99) of the respondents, clearly indicating that most of the women would expect to pay more for a hip protector garment compared to, for example, ordinary underwear. This is useful to know when developing a product design specification, but further investigation into attitudes towards cost is conducted later through telephone interviews with potential product users.

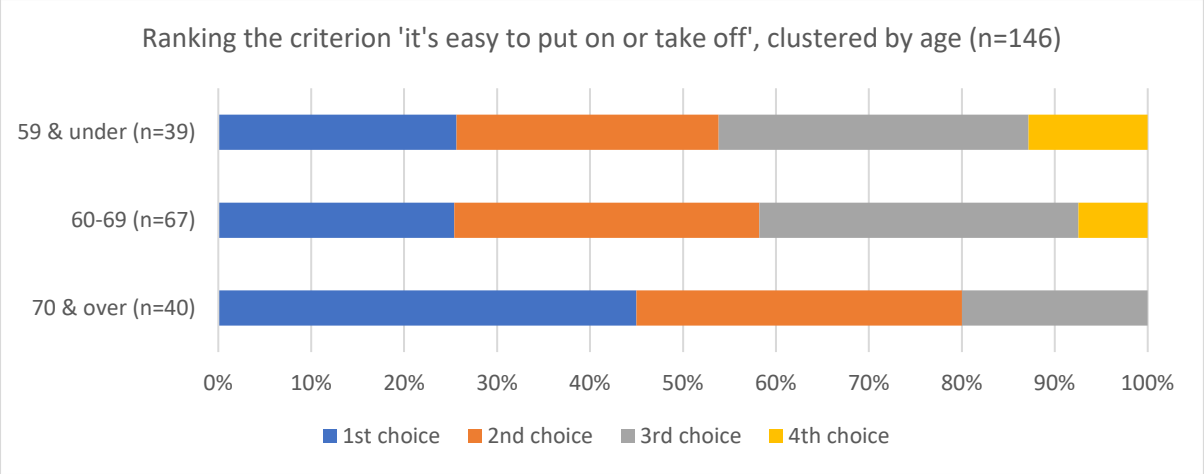


Figure 55: Ranking the criterion 'it's easy to put on or take off', clustered by age.

When the data is clustered by age some nuances occur that are not visible in the overall analysis. The ease of putting on or taking off a hip protector garment is clearly a greater concern for respondents aged 70 and over, compared to younger women (see Figure 55). More women in the oldest age cluster choose this criterion as their first choice (45%, n=18) compared to the garment being comfortable to wear (35%, n=14). This demonstrates how important ease-of-use is for older women especially, and problems that could be faced with tight fitting hip protectors or garments where excessive bending or reaching is needed to put on or take off.

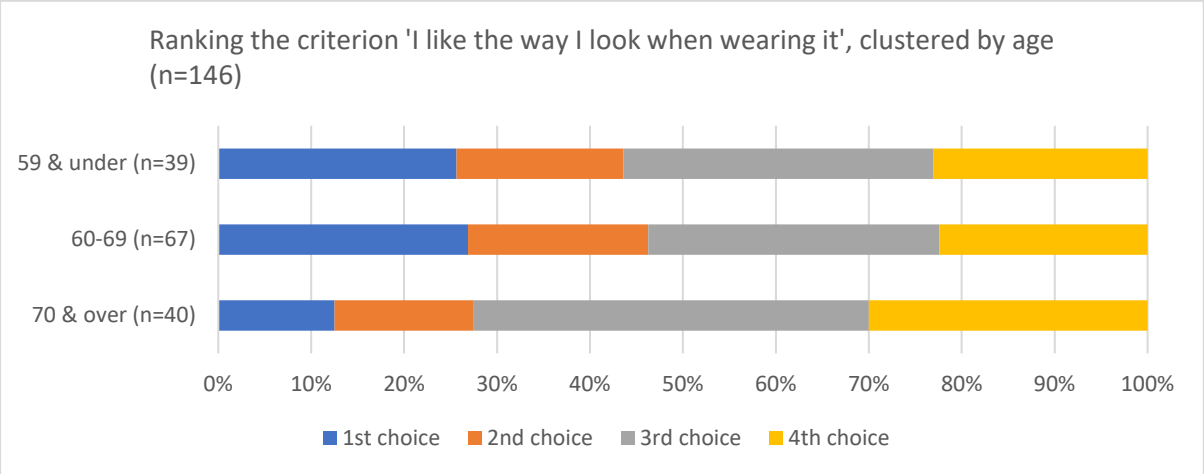


Figure 56: Ranking the criterion 'I like the way I look when wearing it', clustered by age.

When considering how hip protectors might affect personal appearance, a larger proportion of women under the age of 69 ranked 'I like the way I look when wearing it' as first or second choice compared to the oldest age cluster (see Figure 56). This presents a different view to earlier analysis of attitudes towards existing hip protectors from the 70 and over age group. That data showed responses relating to the visceral and reflective nature of underwear hip protectors, for example, were more frequent in this age group compared to younger respondents. However, the high proportion of responses as 3rd choice demonstrates that this is still an important issue for this age group.

4.3.5.4 Reflection

The research demonstrates that if hip protectors are to be worn as often as possible, then designs incorporating different context-dependent styles are needed. This is arguably more important if the hip protector is visible, and it is noted that most respondents would prefer hip protectors that are hidden under clothing. Scenarios such as exercising, shopping, and gardening are signalled as key activities where hip protectors would be worn.

The interest in 'sporty' looking hip protectors reinforces the rationale for a garment designed specifically for exercising in. However, outdoor, physical activities such as gardening could also conceivably be accommodated through a similar garment. The demand for hip protectors for walking in (i.e., long walks or hiking), could also be met this way. A garment designed to reflect this broader context of exercise could be both 'sporty' and 'casual'. This research has explored the visual style of the garment but other technical aspects of the design, such as the type of textiles used, will also be context dependent.

The scenario of work might demand a more sophisticated looking hip protector but obviously not all fields of work require especially formal clothing. A garment that is differentiated from a casual or sporty looking design would, however, provide opportunities for hip protector use in a wider range of contexts. The overall preference for hip protectors hidden under clothing may, of course, supersede this requirement.

Overall, 'simple', 'feminine', and 'understated' are key styling cues for hip protectors for women. It is reasonable to assume a design language based on these terms would apply to visible or hidden hip protectors as earlier research shows that most respondents would still care what a hidden hip protector looked like. It is important to note that the styling terms used in the survey are subjective

and may be interpreted differently. As such, it is more helpful to think of the style preference research as a designers' guide and inspiration, linked to the context of use, than a concrete set of design rules.

Finally, the ranking of hip protector criteria indicates comfort and ease-of-use are universally important, but ease of getting on and off is especially valued by the oldest respondents. This must be carefully considered in the design of new hip protector garments. How hip protectors might affect the way the wearer looks is also a high priority for many women. This resonates with earlier responses calling for hip protectors that are less bulky and more discrete and should equally be factored into the design development when reflecting on visual styles. Although cost is always an important consumer criterion, the data demonstrates that most of the respondents would expect to pay more for a hip protector garment than equivalent regular clothing.

From the analysis of part 3 of the online survey, the following criteria are noted as key priorities for hip protector design:

- Hip protectors that are casual or sporty to accommodate lifestyle activities such as exercising and gardening.
- Hip protectors that are sophisticated and elegant in appearance (in contrast to casual or sporty).
- Hip protectors that are simple, feminine, and understated.
- Hip protectors that are comfortable.
- Hip protectors that are easy to use.
- Hip protectors that are affordable, although with an expectation that the cost is comparable with other specialist or protective clothing.

4.4 Personas

Personas are imaginary characters that represent different user archetypes based on real people who have engaged with the research (Dam and Siang 2024). The constraints presented by the pandemic and national lockdowns made the use of personas an important part of the research process, as engaging with actual participants became more challenging. They helped to frame the design practice towards a specific audience and became a useful tool to evaluate design concepts.

The qualitative insight provided by the online survey revealed patterns that helped to inform preferences and characteristics to shape the personas. I used Cohen's (2006) Four Phases of Adult Development (discussed in 2.1.1) as a framework to develop the personas from Mid-Life Re-Evaluation to the Encore phase. Framing the personas this way challenges ageist attitudes by mediating the development of new hip protector designs, inclusive of younger and older people, that can reflect more positive messages about ageing. Currently, there is a broad discussion on data-based personas but there is a lack of research in the literature relating to designing later-life personas (Schäfer et al. 2019). The development of personas that focus on mid to older age helps to address this issue.

Persona details such as personality, interests, and social environment, were also shaped by comments made in the survey and narratives identified through earlier focus groups and later telephone interviews. Quotations were paraphrased, or taken directly from the survey responses, to shape the personas' attitudes towards hip protectors. A discussion on the development of the personas has been published (Andrews 2023) and is presented in Appendix A.

Overall, this way of developing the personas has extended the breadth of exploration and interpretation of the survey data. By closely scrutinising the qualitative data and reimagining the voices of the respondents through these fictional archetypes, the survey analysis has cultivated tangible 'human centred' outcomes that go further than presenting the findings through charts and graphs alone. The focus groups planned originally, before the pandemic, would have benefitted from feedback on physical samples and prototypes. However, the data to inform the personas would have been quite narrow with far fewer participants at later life stage only. The survey sample size and diversity of age allowed for meaningful development of personas at different life stages.

The five personas, Nancy, Greta, Delores, Wendy and Emma are presented in Appendix I. They are returned to in sections 5.3 and 5.4 as a tool for evaluating the design concepts, particularly relating to performance requirements beyond reducing hip fracture risk, and how sociocultural and lifestyle aspirations can be represented through the materials and garment aesthetics.

4.5 Discussion: Informing the design direction

The insights gathered from industry and clinicians, and potential hip protector users, has helped to form a substantial range of design criteria for the development of improved forms of hip protection. The personas, primarily developed in response to the online survey data, are indicative of the

breadth of audience and potential female users of the product. This human-centred investigation is also underpinned by the earlier contextual review from which a conceptual framework was proposed.

The research indicates that women are at a higher risk of hip fracture (see 2.2.4) but have been underrepresented in the design of many existing hip protectors which have a masculine appearance and present more difficulty in daily use, e.g., pulling up and down to use the toilet (see 2.2.3, 4.2.2, and 4.3.3). Although hip protection for both women *and* men is important, it is time for the paradigm to be flipped and women to be placed at the centre of the design research for hip protectors. In this respect, women will be considered the primary users throughout the design development, with a view to how designs can be made inclusive to all genders.

The proposed design criteria explored through the 'discover' and 'define' phases can now be collated to establish the direction for concept development. The findings from the human-centred design research methods are consolidated in Table 16, triangulating the qualitative data. This process has helped to refine the design criteria for new types of hip protection but also corroborate the findings from different research methods.

Table 16: Consolidation of design criteria for new types of hip protector garments.

Consolidated design criteria	**Criteria established through human-centred design research methods**	**Research methods**
Visual language expressing socio-cultural norms	Hip protectors sensitively designed for more active users in a community setting could help them become more mainstream, normalising their use in later life. This could negate the issues met with older people with dementia unfamiliar with hip protectors and resistant to using them.	4.1.1 Interview with a gerontological physiotherapist
	Hip protectors that were hidden from view and normalised into daily routines would be the least disruptive to residents living with dementia.	4.1.2 Design probe with care home staff
	Hip protectors should have a familiarity, and align, aesthetically and ideologically, with clothing types understood and valued by the user.	4.1.4 Interview with a fashion designer
	New designs of hip protectors should consider cultural norms of gendered clothing, especially relating to underwear garments.	4.2 Focus groups with active older people

Consolidated design criteria	Criteria established through human-centred design research methods	Research methods
	Reflective and inclusive of different genders.	4.3.3 Attitudes towards underwear and outerwear hip protectors (Part 1)
	Modern style that could take cues from contemporary fashion or sportswear.	4.3.3 Attitudes towards underwear and outerwear hip protectors (Part 1)
	Avoidance of visual characteristics related to hospital patient clothing.	4.3.3 Attitudes towards underwear and outerwear hip protectors (Part 1)
	Hip protectors that are sophisticated and elegant in appearance (in contrast to casual or sporty).	4.3.5 Re-thinking hip protection (Part 3)
	Hip protectors that are simple, feminine, and understated.	4.3.5 Re-thinking hip protection (Part 3)
Easy to get on/off with reduced mobility/dexterity	Styles of hip protector, such as wrap around, could be advantageous for people with limited mobility/dexterity so they don't need to be pulled up and down.	4.1.2 Design probe with care home staff
	Hip protectors should be easy to put on and take off, especially in relation to using the toilet.	4.2.1 Focus groups with active older people
	Easy to use.	4.3.3 Attitudes towards underwear and outerwear hip protectors (Part 1)
	Hip protectors must be easy to use, especially for people with reduced mobility and/or hand strength and dexterity issues.	4.3.4 Attitudes towards inflatable hip protectors (Part 2)
	Hip protectors that are easy to use.	4.3.5 Re-thinking hip protection (Part 3)
Discreet/not bulky	There is potential for padded belt type hip protectors that can be worn more discretely under clothing.	4.2 Focus groups with active older people
	Neat and compact, not bulky.	4.3.3 Attitudes towards underwear and outerwear hip protectors (Part 1)
	Discreet or hidden from view.	4.3.3 Attitudes towards underwear and outerwear hip protectors (Part 1)
	Shaped to form of the body to make it less obvious.	4.3.3 Attitudes towards underwear and outerwear hip protectors (Part 1)
	Hip protectors should be discreet and not bulky.	4.3.4 Attitudes towards inflatable hip protectors (Part 2)
Affordable	Hip protectors must be as affordable as possible to be accessible to a wide	4.1.1 Interview with a gerontological physiotherapist

Consolidated design criteria	Criteria established through human-centred design research methods	Research methods
	proportion of the population on potentially low and fixed incomes.	
	Hip protectors must be as affordable as possible to be accessible to as many people as possible.	4.3.4 Attitudes towards inflatable hip protectors (Part 2)
	Hip protectors that are affordable, although with an expectation that the cost is comparable with other specialist or protective clothing.	4.3.5 Re-thinking hip protection (Part 3)
Comfortable	Hip protectors must be comfortable to wear for extended periods of time with pads that don't dig in when sitting.	4.1.2 Design probe with care home staff
	Hip protectors should be lightweight and comfortable but also evoke confidence that they are effective.	4.2 Focus groups with active older people
	Comfortable	4.3.3 Attitudes towards underwear and outerwear hip protectors (Part 1)
	Hip protectors that are comfortable.	4.3.5 Re-thinking hip protection (Part 3)
Relate to sportswear	Hip protector garments with a 'sporty look' could be more appealing to older users.	4.1.1 Interview with a gerontological physiotherapist
	Sportswear is a rich area for investigation in terms of older markets and clothing that empowers its users.	4.1.4 Interview with a fashion designer
	Modern style that could take cues from contemporary fashion or sportswear.	4.3.3 Attitudes towards underwear and outerwear hip protectors (Part 1)
	Hip protectors that are casual or sporty to accommodate lifestyle activities such as exercising and gardening.	4.3.5 Re-thinking hip protection (Part 3)
Different scenarios of use / contexts	Different types of hip protectors could be worn during the day and at night time, appropriate to the context of use but also reinforce normal daily routines.	4.1.2 Design probe with care home staff
	An awareness of intersectionality is needed to acknowledge the differences among potential hip protector users.	4.1.4 Interview with a fashion designer
	Potential to be worn under or over existing clothing.	4.3.3 Attitudes towards underwear and outerwear hip protectors (Part 1)

Consolidated design criteria	Criteria established through human-centred design research methods	Research methods
Lightweight	Hip protectors should be lightweight and comfortable but also evoke confidence that they are effective.	4.2 Focus groups with active older people
	Sustainable, natural fibres that are breathable and lightweight.	4.3.3 Attitudes towards underwear and outerwear hip protectors (Part 1)
	Lightweight inflatable surfaces with good force attenuation properties could be integrated into a passive system to negate cost, inconvenience, and safety concerns of airbag hip protectors.	4.3.4 Attitudes towards inflatable hip protectors (Part 2)
Perceived and actual effectiveness	Hip protectors should be lightweight and comfortable but also evoke confidence that they are effective.	4.2 Focus groups with active older people
	Reliable hip protection.	4.3.3 Attitudes towards underwear and outerwear hip protectors (Part 1)
Use with incontinence products	Hip protectors that comfortably accommodate the use of incontinence products would be beneficial for some.	4.1.1 Interview with a gerontological physiotherapist
	A belt type hip protector more easily accommodates incontinence underwear.	4.1.1 Interview with a gerontological physiotherapist
Range of sizes/adjustable	Hip protectors must be available in a range of sizes but adjustability could help to accommodate changes in body size due to weight loss or gain.	4.1.1 Interview with a gerontological physiotherapist
	Hip protectors must be available in a range of sizes but adjustability could also help to accommodate variation.	4.1.2 Design probe with care home staff
	Hip protector garments must meet the physical requirements of ageing bodies and the natural changes to body shape that occur.	4.1.4 Interview with a fashion designer
Easy to launder/launder less	Hip protectors worn over clothing negate the need for frequent laundering.	4.1.1 Interview with a gerontological physiotherapist
	A belt type hip protector negates the need for frequent laundering and integrated pads would prevent them from being separated and lost.	4.1.2 Design probe with care home staff
Other desirable features	Range of colours.	4.3.3 Attitudes towards underwear and outerwear hip protectors (Part 1)
	Sustainable, natural fibres that are breathable and lightweight.	4.3.3 Attitudes towards underwear and outerwear hip protectors (Part 1)

Consolidated design criteria	Criteria established through human-centred design research methods	Research methods
	When dressing with a hip protector garment it would be beneficial to provide a means of visually indicating that the pads are positioned correctly.	4.1.1 Interview with a gerontological physiotherapist

Hip protectors may be beneficial to users at different life stages, with quite different needs and abilities, and therefore used in different environments and scenarios. Reflecting on the personas (see 4.4) and the scenarios where hip protectors might be used (see 4.3.5), a discreet hip protector garment that Nancy wears as often as possible could potentially be quite a different type of product to one that Wendy only feels the need to wear when exercising. With both users, the demands on product performance and aesthetics will be dependent on the environment of use and their individual circumstances. The design development phase must embrace the different contexts of use made apparent through the research and recognise that the optimum design solution may well be more than one type of product. This is where the multiple 'answers' to the research question, discussed in the methodology (see 3.1), can be investigated.

With a robust set of criteria determined, validated via the frequency of occurrences through the mixed methods approach, the design development can begin to emerge in response to the overarching research question. This is an appropriate point to evaluate the proposed design direction through the lens of the conceptual framework established after the contextual review:

Hip protector design informed by both medical and social models of development, reflecting physical and psychological needs of users.

Literature from the fields of medicine, nursing, and gerontology (see 2.2) and the insights from clinicians (see 4.1) provided a meaningful starting point to explore the potential physical needs of older adults and hip protector users. Key criteria relating to the functional requirements for hip protector garments are well reported but the barriers to their acceptance suggest that many existing products underperform in some or all areas (Sims-Gould et al. 2014).

Hip protectors must reduce the risk of hip fracture, which means reducing the impact force caused by a fall at the femoral neck to below a 2.5kN threshold (Mills 1996). Although research ethics constraints have forbidden functional aspects, such as comfort and ease-of-use, to be evaluated by older participants, simulated mechanical tests can at least investigate if impact absorbing materials

meet the functional specification above. These were conducted and are reported on later in the thesis (see 5.4.1).

The comfort of wearing hip protectors (including not causing skin irritation), and the ease of getting them on or off, are critical criteria to meet the physical needs of users. Both these factors could be contingent on the style of hip protector. For example, care home staff suggested the wrap around closure of the HiP padded belt would be easier to put on compared to pulling up the Fall Safe underwear (see 4.1.2). Similarly, perceived ease of use and comfort were 'behavioural' themes derived from several comments made about the padded belt hip protector in the online survey (see 4.3.3).

Within a medical model of development, the HiP padded belt hip protector appears to address some of the issues relating to comfort and ease of use, and certainly has the potential to perform better in these areas compared to the Fall Safe underwear. However, it is vital that a social model of development is also applied. The psychological needs of hip protector users, particularly relating to their self-image, confidence to be active, and agency, are critical. In the online survey, the 'visceral' and 'reflective' comments relating to changes to the appearance of the padded belt hip protector, demonstrate the scope for a more sensitive response. In particular, a product that was less bulky and more discreet, with different colour options, with a more sporty or feminine style, would be preferred (see 4.3.3).

Hip protectors that are easier to use will offer the wearer greater agency and independence. However, much of the psychological needs of hip protector users will be met through better understanding and consideration of the meanings these garments can express.

Hip protector design that explores the cultural negotiation of their meanings, recognising they are neither fixed nor absolute and are context dependent.

The meanings expressed through the appearance of current types of hip protectors can be considered in terms of the messages the wearer would like to (or not like to) communicate to others (Barnard 2002; Campbell 2013). However, with hip protectors hidden under clothing, those meanings are internalised by the wearer (or perhaps only shared with a partner or carer). Here, the question is whether the garment aligns with their sense of self and if the meanings they interpret from it defy their own identity. Underwear hip protectors are, in effect, *specialist underpants*, a notion already associated with incontinence and other issues related to the most intimate parts of our bodies. This may well impact on acceptance of these garments for some people, as suggested through terms

identified earlier in the word cloud analysis, such as ‘medical’, ‘clinical’, ‘elderly’, and ‘old person’. Underwear garments are used for hip protection purely for the convenience of locating the protective padding over the hip joint. Removing the association between hip protection and underwear, and designing different types of protective garments, could improve the receptivity of these products. Indeed, the preference towards the padded belt hip protector noted in the online survey (see 4.3.3) is indicative of this, especially when 42% (n=62) of respondents noted that they would wear a padded belt hip protector under their clothes. This preference was also shared by the participants in the focus groups with active older people (see 4.2).

Hip protectors worn under clothing can affect the wearer’s body shape making their hips look wider or lumpy. This is a well reported barrier to their use, both in the literature (Myers et al. 1995; Chan 2000; Hubacher and Wettstein 2001; Patel et al. 2003; Forsén et al. 2004; Thompson et al. 2005; Honkanen et al. 2006; Blalock et al. 2010; Cameron et al. 2011), and in the research presented in the earlier sections. The technological solution could be to develop impact absorbing materials that are thinner without compromising on force attenuation capabilities. This is challenging, as Laing et al. (2011) have found, thicker pads tend to offer higher levels of impact protection. The socio-cultural solution could be to leverage an understanding of how the meanings conveyed through clothing are context dependent. Scenarios where hip protection could be worn, such as gardening or doing exercise (see 4.3.5), could warrant a garment designed with the outdoors or physical activity specifically in mind. If worn so they are visible over clothing, these garments could have an appearance akin to sports or leisurewear that naturally aligns the wearer with the context of use.

Clothing brands are an important cultural signifier that particularly convey material and social status or indicate that the wearer belongs to specific sub-culture (Elliott 2018). The meanings associated with a particular brand could have a significant impact on the acceptance and desirability of hip protector garments. Imagine a Nike hip protector, for example, rendered in a subtle colour palette with the familiar ‘swoosh’ embellishment neatly set above the lower edge of the pad on one side. The brand embodies the notion of speed, strength, and movement, but is also purposefully shifting from pure sport to holistic fitness and wellness (Nike 2023a). The idea of a Nike hip protector garment for active-agers may not be too farfetched for a brand whose culture of innovation, “has lead us to products and services that are increasingly inclusive and consider body, mind and life” (Nike 2023a). Although the exploration of brand values is outside the scope of this research, it must be recognised that companies like Nike could hold a powerful sway in motivating users to engage with hip protection. However, company branding must be met with some caution as research suggests that active agers are less accepting of visible logos on garments (McCann 2015).

The opportunities for hip protection in the context of sportswear is well established through the earlier research (see 4.1.1, 4.1.3, 4.3.3, and 4.3.5). This relates to garments worn for exercise, but also the broader market of athletic leisurewear. This is a clear priority for the development of a visual language of new types of hip protection that also expresses 'simple', feminine' and 'understated' aesthetics. Sportswear bridges the functional requirement for comfortable clothing with a forgiving fit, with a garment that inspires confidence for activity and movement. In relation to the older population at risk of falls, this is particularly important to motivate community dwelling adults to engage with hip protection, where compliance is especially low (Santesso et al. 2014).

Hip protector design as critical gerontology, challenging ageist attitudes and developing new products that empower healthy ageing.

In the broadest sense, hip protection could be categorised into that which can be worn temporarily to engage with a specific activity (e.g., doing exercise), and that designed to be worn constantly, integrating with ordinary, day-to-day living. The former is reflective of the padded belt hip protector (which can be quickly put on over clothing and easily removed), and the latter relates to the underwear hip protector examples, discussed earlier (although padded belt hip protectors could be worn for day-to-day living too). Although the online survey indicated that younger respondents were more receptive to hip protectors worn visibly over clothing than older women, this was not categorical, and preferences for both types of hip protection were recorded across all age groups (see 4.3.3). From a critical gerontological perspective, this shifts the emphasis away from 'age' as a determinant for wearing hip protectors, and places the focus on 'fall risk', regardless of age. In doing so, care must be taken not to conflate the comorbidities associated with fall risk with 'patient scripted' clothing (Topo and Iltanen-Tahkavuori 2010). New types of hip protection must embrace a visual language in keeping with cultural norms, that give the wearer confidence to be active and – most importantly – be seen by others when wearing the garment.

There is tension, however, between the approaches of visible or hidden hip protection. It is clear from the earlier research that there is a strong demand for hip protectors that are not visible when worn. With hidden hip protection, however, the narrative of hiding or disguising disability, so as not to be 'othered', continues to perpetuate. It becomes harder for new products to challenge ageist attitudes if people are not visibly seen to be engaging with them. The introduction of new types of hip protection may also need to coincide with a cultural shift towards more proactive approaches to healthy ageing. As noted by Pat O'Brien (see 4.1.1), hip protectors with a sporty look may be enough to encourage older people to wear a protective garment if it becomes normalised. This could also

help to tackle resistance to hip protectors due to a lack of understanding or acceptance of fall risk (Sims-Gould et al. 2014). Perhaps the attitude of the younger online survey respondents, who appear more receptive to visibly worn hip protectors, will continue as they age and reach later life stages.

In the contextual review, I explored the notion of 'garments of empowerment' and 'garments of dependency' by comparing the Dainese snowboarding hip protector to the HipSaver product. The notion of empowerment responds to ideas of strength, confidence, and agency, and the appearance of the Dainese product invites a sense of action and physical dynamism associated with performance sportswear. However, this outwardly bold expression is not for everyone, and Twigg's (2013) research with older women demonstrated that most of the clothing choices they made were based on conformity rather than wanting to stand out. Reflecting the demands for discretion, and preference for disguised or hidden hip protectors, new types of garments could manifest a kind of *quiet* empowerment that embraces a pro-active, yet understated, approach to living and ageing well. Afterall, along with 'simple' and 'feminine', 'understated' is one of the key style preferences highlighted in the online survey (see 4.3.5).

5 Hipwear: Develop and deliver phases

In this chapter, I present the practice-based design research engaging predominantly with the second two phases of the Design Council's Double Diamond: develop and deliver. It begins with an overview of the methods that are integral to the design practice. These relate to the visualisation and three-dimensional development of design concepts. Sections 5.2, 5.3 and 5.4 investigate the iterative development of design concepts through idea generation, material experimentation, and user feedback, engaging with the principles of Action Research. The project-grounded approach uses the conceptual framework theorised in section 2.4 as a critical lens to evaluate design concepts as they emerge. In the final section of this chapter, I present design proposals for the Hipwear concept.

5.1 Design methods

The research *through* design primarily consists of the methods engaged in design exploration. This is the creative response to the research question underpinned and informed by research *into* design that has framed the design specification (see 4.5). Design exploration is also the territory in which design ideas are developed iteratively and evaluated against the three key tenets of the conceptual framework. Feedback on concepts (i.e., visualisations or physical prototypes) from potential hip protector users has also fed directly back into the iterative development process, aligning with the principles of Action Research.

Design exploration began during the 'define' phase of the project in relation to initial concepts and 3D development. This early investigation preceded more formal, iterative design development by exploring the physical qualities, limitations, and potential applications of a range of materials and fabrication methods. The experimentation through this process informed 'ways of doing' to produce a range of artefacts to inspire and direct future design proposals. Later, during the 'develop' and 'deliver' phases – and building on earlier experiments – the design exploration was more focused on the development of new hip protector garments.

Drawing on my experience as a product designer, I have employed a range of different methods throughout the design exploration, each serving the need to visualise, interpret, and evaluate concepts as they emerge. The methods broadly include:

- Sketching and visualisation

- Sketch modelling, test pieces and prototyping
- Computer Aided Design (CAD) and digital prototyping

An overview of these approaches is presented below. However, as the methods are such an integral part of the design practice itself, the relationship between 'the doing' and how this informed further investigation is discussed in more detail in sections 5.2, 5.3, and 5.4.

5.1.1 Sketching and visualisation

Eissen and Steur argue that sketches are, "an integral part of the decision-making process, used in the early stages of design, in brainstorming sessions, in the phase of research and exploring concepts, and in presentation" (2007: 7). I use sketches to visualise and develop design ideas, typically during the infancy of a design concept, or as part of the evaluation of a model or prototype, speculating on further development of the idea.

Through my experience in design practice, I prefer using a 0.7mm fine line black pen, in a sketchbook or A3 layout paper, for simple line drawings. My sketches are primarily motivated towards understanding the physicality of an object, often exploring specific details rather than holistic design concepts. Diagrammatic and quick suggestive sketches are most often used in this respect, which then quickly lead to the development of sketch models, test pieces and mock-ups.

As a product designer, I have visualised hip protector garments as 'wearable objects' on body shapes broadly representative of the target users. This differs from the method commonly adopted by fashion designers where garment concepts adorn exaggerated and stylised interpretations of a figure "imbued with associations and ideals" (Hopkins 2018: 46). In female fashion illustration, the figure typically projects greater height to enhance the drape and proportion of clothes. Hopkins notes that, "much of the additional height is gained by extending the legs, with some height added to the neck and a little added to the torso above the natural waist" (2018: 46). These unnatural proportions, however, are not helpful when considering the ergonomic and performance requirements of hip protectors.

I also visualised design concepts using digital tools to provide more sophisticated ways of communicating the ideas to stakeholders, such as focus group participants and industry partners. For example, the Under/Over/Outer concept boards (see 5.2.3), and early visualisations of Hipwear design concepts, were produced using Photoshop image editing software and InDesign desktop publishing software. These are industry standard design tools produced by the American software

company, Adobe (2024d). CAD software was also used to generate photorealistic renders of design proposals, but this will be discussed in more detail later.

5.1.2 Sketch modelling, test pieces and prototyping

Translating ideas expressed through sketches into three-dimensional objects is a critical part of the design process. The evolution between 2D and 3D engages with the Action Research cycle between the 'formation of abstract concepts', to 'testing implications of concepts'.

Sketch modelling is the first step in translating sketched ideas into three-dimensional forms, and I used this method to investigate how concepts for garments worn over the hips would translate into fabric or other flexible materials. Sketch models provide insight into the evolving form of a product and, "allow for quick an effective evaluation of aesthetics, ergonomics, functionality, usability, proportion, and packaging and configuration options" (Milton and Rodgers 2013: 95). They generally consist of low-cost materials, such as paper or card, and can often be crude and not fully representative of the intended design.

Material experiments led to the development of a range of test pieces, aligned with concepts relating to the impact protection aspect of the garment design. This consisted of early experiments to investigate material properties and making processes, and later work to explore energy absorbing properties. In all cases, the inquiry engaged with the research question by considering the garment performance requirements and visual language.

To be time and cost effective, the test pieces were produced as small samples that could be evaluated before scaling to larger proportions, if appropriate, for hip protection. I evaluated the test pieces derived from earlier design concepts from a usability perspective, in terms of comfort and aesthetics, hypothesising on their energy absorbing qualities based on the contextual review. However, test pieces that were developed later were subjected to mechanical impact testing when, by that stage in the project, I had developed drop testing equipment for this purpose. I fabricated all the test pieces in Falmouth University workshops (apart from some outsourced 3D printing). A summary of methods is tabulated in Appendix J and are discussed further, in the context of the design practice, in sections 5.2, 5.3, and 5.4..

Mock-ups are rudimentary prototypes, made from easily fabricated materials, used to evaluate the physical interaction, scale and proportion of design concepts (Milton and Rodgers 2013). I developed these early prototypes as an interim stage between test pieces and more refined prototypes. These

have supported exploration into the relationship between the hip protection element and the garment as a whole. Mock-ups have included inflatable surfaces that wrap around the hips, and garment concepts fabricated in calico and Lycra, as a development from the earlier test pieces. I used both sewing and seam bonding fabrication methods.

The relationship with the industry partner, DM Orthotics, has allowed for more refined prototypes to be developed quickly from these mock-ups. These have included: a garment that contains an inflatable surface that wraps around the hips (see 5.2.2); a padded belt garment worn under clothing (see 5.2.1); and several iterations of vest garments with integrated hip protection (see 5.3 and 5.4).

5.1.3 Computer Aided Design (CAD) and digital prototyping

CAD software has been a critical tool used to develop design concepts and visualise details that would be difficult to evaluate through sketching and model making alone. I have used CAD software to develop manufacturing information, in the form of drawings and 3D models, to produce manually fabricated garments and elements made using subtractive (e.g., laser cutting) and additive (e.g., 3D printing) digital manufacturing processes. Software has also been used to explore different types of fabric, colours, and detailing, and produce photorealistic renderings of design proposals. These have been vital to communicate design ideas to gain feedback from potential hip protector users.

Milton and Rodgers (2013) note the value of using CAD for the quick exploration of design ideas, materials and textures, and how it provides a more cost-effective approach than producing physical models. However, they are right to express that, “there is no substitute for a well-resolved tangible physical model that consumers and clients can see, feel and engage with” (Milton and Rodgers 2013: 162). In this respect, I have placed an emphasis on physical prototyping throughout the development process.

I chose different types of CAD software that were appropriate to the specific task. All the CAD packages are used in professional practice across the design industry. Some of the software was selected due to my prior experience using it, such as Autodesk Inventor and Autodesk AutoCAD. Programs such as Autodesk Netfabb, nTopology, Formlabs PreForm, and CLO, had to be learnt. All the CAD programs were used under academic licenses affiliated to Falmouth University. Use of CAD, and outputs, throughout the design process is summarised in Appendix K and discussed further later in the context of the design practice.

In addition to 3D printing and laser cutting technologies used for prototyping, I also investigated 3D scanning as a method for capturing body shape data that could inform the manufacture of bespoke hip protection garments. The contextual review identified several examples where 3D scanning techniques were used to capture body size data to develop bespoke products to fit individual users. This was noted particularly within the sports industry to produce high performance apparel or for the development of sports protection equipment, such as those produced by German manufacturer, Ortema. This research established the potential for 3D body scanning of people who are vulnerable to falls. Data extracted from 3D scans of a user's hips and waist could directly inform the size and shape of a hip protector (the pads, or even the whole garment) using computer software. A bespoke fitting hip protector garment could not only be more comfortable to wear but could also increase efficacy due to more accurate positioning of the protective pads over the greater trochanter (Yahaya et al. 2021).

The work conducted was primarily to understand the potential and limitations of the technology and establish an approach as proof of principle. My focus was on body scanning to inform the size and shape requirements for the protective pads, not the whole garment. However, as discussed earlier (see 2.3.4) the principle of 3D body scanning to generate personalised avatars to inform the overall garment size and fit could be developed later. I used a fashion mannequin as the scanning subject, negating the need to recruit a willing participant for these experiments. The mannequin provided a static subject which is a necessity to capture accurate scan data. However, it is noted that standing still for any length of time for live participants may be problematic, especially for frail older adults, and measures to provide support, such as a handrail or even scanning in a seated position, would need to be considered. It is also important to note that 3D body morphology of the mannequin used for scanning is not representative of most female body shapes, regardless of age. This is a limitation that is discussed further in section 5.2.1.1 and 5.3.1.3 where the challenges in the variations of body shape among older people are expanded upon.

I used Falmouth University's hand-held Artec 3D scanner (Artec 3D 2024) to investigate the process and viability of scanning a user's waist and hips (see Appendix L). By scanning a mannequin, the data was used to create a 3D CAD file onto which geometry for a hip protector pad can be designed. The process explored how the shape of the pad could directly derive from the actual shape of the user. However, a fundamental problem with using 3D body scan data in this way is it only captures the hip surface shape in one position. The reality, of course, is that the hip is dynamic and subtle contour changes at the skin surface occur when we're walking, sitting, standing, etc. Using flexible 3D printed materials could provide a way of accommodating the shape of the hip as the user moves. A practical investigation into this technology begins in section 5.2.1.3.

5.2 Initial concept investigation

The initial concept investigation responded to the findings gathered through the contextual review, insights from industry and clinicians, and focus groups with active older people. The research question – especially how hip protectors can embody a visual language that sensitively reflects sociocultural and lifestyle aspirations – was driving this inquiry. This part of the project occurred before the coronavirus pandemic when there were no lockdown or social distancing restrictions. This was also before the online survey had been initiated, so the response was to design criteria that were still evolving, and the personas had not yet taken shape. However, the conceptual framework provided a solid foundation for which initial design concepts could emerge in response.

During the initial concept investigation, I explored innovation opportunities by challenging the traditional format of hip protection. If underwear hip protectors are so problematic, in what other ways can clothing facilitate hip protection? And how can it do this in ways that are not stigmatising or debilitating? As ideas in response to these questions began to coalesce, I started to develop initial experiments to explore the potential of materials and processes aligned to these approaches.

5.2.1 Hip belt

Difficulty of use (getting on and off due to physical frailty) and loss of independence, especially related to using the toilet (Sims-Gould et al. 2014), were factors underpinning the idea of a hip protector belt worn under or over clothing. By treating the hip protection as an element independent from the user's underwear, the need to pull up or down is negated when using the toilet. A hip protector belt that could be fastened at the front overcomes issues of having to bend and step through an underwear hip protector or pull up a tight-fitting garment. This was an observation made by the staff at Mountford House (see 4.1.2). The focus group participants (see 4.2.2) also all agreed that tight fitting fabric, such as Lycra, would make using the garment very difficult to pull up and down, and would not be acceptable.

The demand for a padded belt type hip protector designed to be worn *under* clothing first became apparent through the focus groups with active older people (see 4.2). Despite responding positively to the appearance of the HiP product, the female participants agreed that they would not want it to be visible and risk being perceived as old and frail, reflecting the findings of Tavener-Smith and De Vet (2006). The need for discretion when wearing a hip protector was paramount for this group. This

point was reinforced later through the online survey where 55% (n=80) of respondents said they would prefer to wear a hip protector hidden under their clothes, and 43% (n=62) said that if they were to wear a padded belt hip protector, they'd also wear it under their clothes (see 4.3.3).

5.2.1.1 Initial sketches and modelling

Initial design ideas naturally began by responding to the issues reported with existing types of hip protectors. Early sketches (see Figure 57) explored the potential of a hip protector belt in both the under and outer wear contexts.

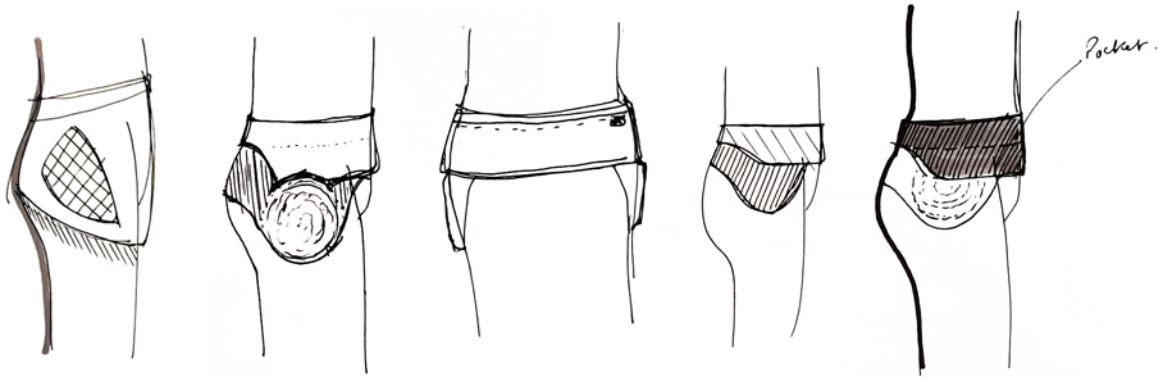


Figure 57: Early sketches exploring hip protector belt concept.

In particular, I was interested in exploring the visual format of the garment, considering the relationship between the belt and padded region. The notion of a pocket integrated into the belt, to extend its functionality, was also first considered at this stage and is later explored in the Hipwear OVER discussion (see 5.2.3.3).

This quickly moved into a three-dimensional investigation to understand the potential forms of a hip protector belt. Through sketch modelling, I used paper and tape to create the shape of the garment directly onto a mannequin (see Figure 58). The fashion retail mannequins available for this purpose were not representative of an ageing female body, or indeed the mean average size and shape. Common changes to the body due to ageing include a wider waist, expanded stomach, rounded shoulders, and a lower bust (Goldsberry et al. 1996 cited in Twigg 2012) However, the mannequin offered an adequate starting point to build a paper sketch model from. When removed and laid out flat, the model provided an approximation of the geometry needed to inform the development of a

fabric pattern, with an understanding that adjustments would be needed to accommodate different body shapes and sizes. For example, the mid hip circumference (measured horizontally around the hips 10cm below natural waist level) for UK women ranges from 859mm (5th %ile) to 1166mm (95th %ile) (Department of Trade and Industry 1998).

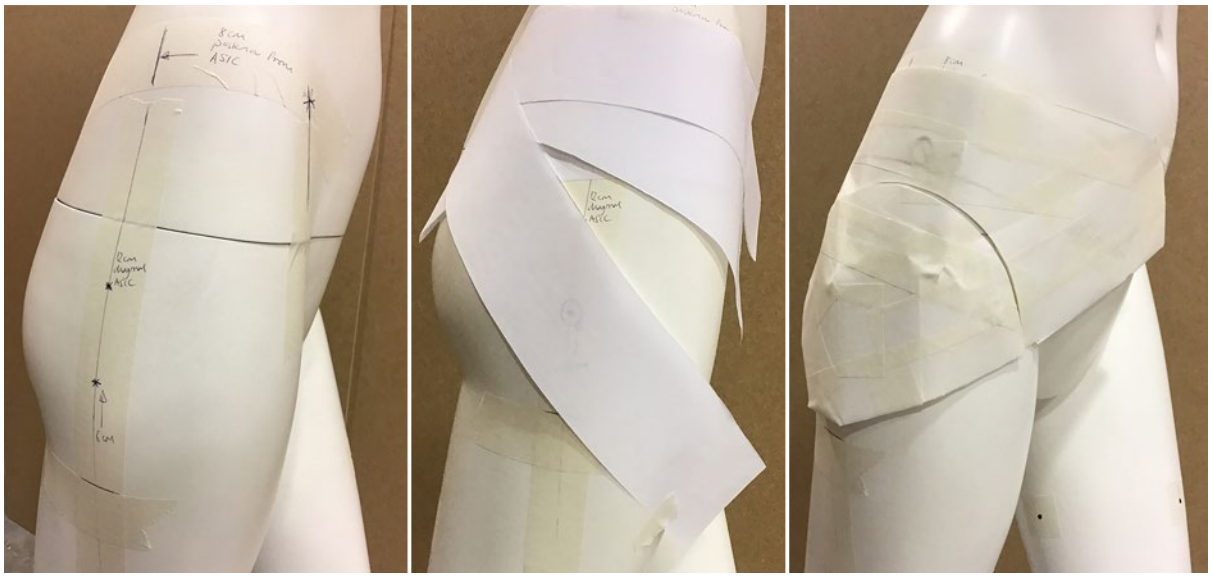


Figure 58: Approximating greater trochanter position and building a paper hip protector belt model.

The position of the greater trochanter had to be approximated owing to the lack of skeleton found inside retail mannequins. In a study examining if hip protectors are correctly positioned in use, Minns et al. (2007) determined that on a female adult standing, the centre of the greater trochanter lies on the coronal plane (a notional vertical plane that runs from side to side, centrally dividing the body into anterior and posterior sections) approximately 6cm above the crotch. This was marked on tape applied to the mannequin with an approximation of the position of the coronal plane. To ensure a hip protector pad would cover the greater trochanter, and the pad centre is likely to be close to the greater trochanter centre, Minns et al. (2007) suggest:

- The lower edge of the pad should be positioned 2 – 4cm below the plane of the crotch.
- The pad should have a vertical length of more than 16cm.
- The pad should be wider than 6cm around the centreline of the coronal plane.

Figure 59: Scan of paper model under pattern outline to inform the shape of the prototype.

I used these dimensions to define the area of the hip surface where the paper sketch model was built. For efficiency, only the right-hand side of the paper model was developed as the left side would be the mirror image. When flattened, the model was digitally scanned, providing an image that was traced to produce a vector drawing as a pattern outline which was later refined in AutoCAD (see Figure 59). This early exploration of the belt concept, through sketching and model making, triggered initial material investigations, especially relating to 3D printing, which will be discussed further later in this chapter.

5.2.1.2 Prototyping a belt

This process also led to the development of a prototype belt garment, produced by DM Orthotics, to explore as a proof of concept (see Figure 60). This iteration of a hip protector belt was made from black polyester blend stretch fabric with an elasticated waist band. It was designed as a step-through garment, akin to putting on underwear, although could also be developed with a front closure mechanism, such as Velcro. However, responding to the need for a padded belt garment worn *under* clothing, its appearance was developed to look like underwear and be worn next to underwear. Reflecting on the demand for more feminine hip protectors, the garment could be embellished further, for example with lace covering over the wide padded region, or edge trim. A precedent already exists for this in the design of some padded bras and the concept is discussed later with focus group participants (see 5.2.3.2).

Figure 60: Hip belt prototype fabricated by DM Orthotics.

Figure 61: Hip belt prototype showing foam padding removed from inside pocket.

As with current underwear hip protectors, this garment was designed with internal pockets which the protective pads can be slipped into but easily removed for laundering (see Figure 61). The pads were produced using 9mm polyester backed soft foam, at this stage, simply to replicate the thickness of a material such as the Poron XRD foam used in Protex's HiP hip protector.

The investigation into energy absorbing materials in the contextual review (see 2.3.3) explored five different types of materials (including Poron XRD) that could be employed as protective padding. However, inspired by Adidas's Futurecraft 4D project (Carbon 2017)(see 2.3.4), I was keen to explore the potential of flexible 3D printed lattice structures as a viable alternative to traditional foam hip protector pads. The opportunity for soft, lightweight, and breathable pads that could be customised to an individual's body size and shape were the key drivers. The literature investigating 3D printed energy absorbing structures developed considerably after the outset of this PhD research project (Isaac and Duddeck 2022) and has informed the later investigation.

5.2.1.3 Investigating flexible 3D printed lattices

The initial 3D printing exploration began by understanding how to digitally generate lattice structures and the different methods available to 3D print these parts in flexible materials. Flexible 3D printed lattice structures are already shown to display good force attenuation properties (Brennan-Craddock et al. 2012; Habib 2020; Isaac and Duddeck 2022; Carbon 2024a). The focus, at this early stage, was therefore less on the lattice geometry and impact absorption, but the implications of the visual and tactile qualities of 3D printed lattices materials for hip protector pad design. Fundamental to this, was learning how to produce flexible 3D printed lattices.

Autodesk Netfabb software is used to prepare 3D prints and simulate additive manufacturing (Autodesk 2024a). The 2019 version of the software included 24 selectable lattice structure designs that could be designated to replace any solid internal volume on a 3D printed part. The primary purpose of this tool is to reduce the amount of material needed to build the part and consequently also reduce the time it takes to build. The software was integrated into Autodesk Fusion 360 in January 2021, but was originally an independent program (All3DP 2022).

I used Netfabb to develop a series of sample blocks, sized 50x50x20mm, that could be 3D printed in different flexible materials, to evaluate their texture, flexibility, and overall feel. Instead of using the software to create a lattice fill in an internal void in the part, I designed the blocks with square shaped lower and upper surfaces with the lattice sandwiched between and exposed on four faces.

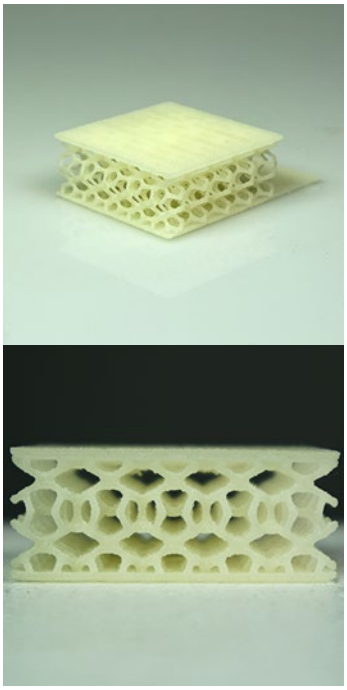
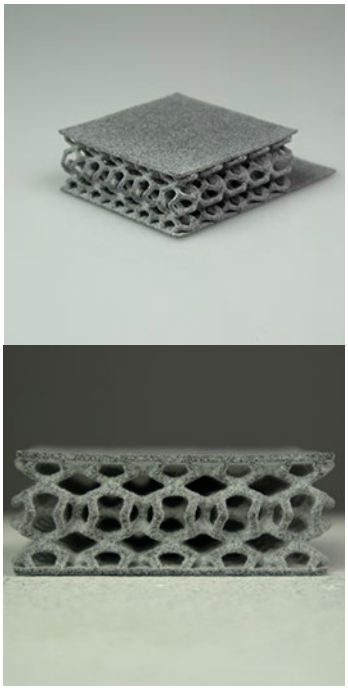
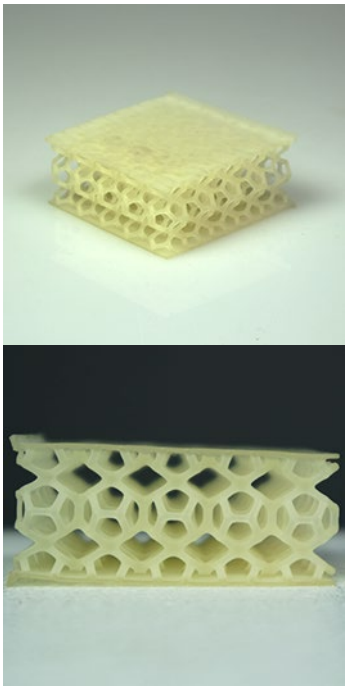
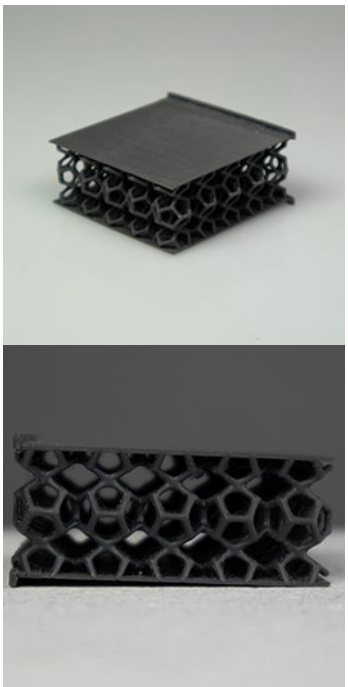
This allowed for visual inspection of both the lattice and the junction with the surface on the 3D printed part.

I explored three additive manufacturing processes to produce the sample blocks (see Table 17): Selective Laser Sintering (SLS), Multi Jet Fusion (MJF), and Stereolithography (SLA). These technologies are all appropriate to produce fine detailed or intricate parts, such as lattice structures. SLS and MJF both use powdered materials as a starting point. SLS uses a laser to fuse the material together whereas MJF uses a fusing agent with added heat to bond the powder and create the part (3D Print UK 2016). Like SLS, SLA also uses a laser, however, it cures a liquid resin instead of a powder. Parts produced using SLS and MJF technologies were outsourced to online 3D printing service, i.materialise, as Falmouth University did not own these machines.

Following design guidelines (i.materialise 2024a), I designed the parts with 1mm wall thickness and a minimum gap of 5 mm between the lattice beams to allow any unfused powder to be removed. The 'Kelvin cell' (a polyhedron composed of six square and eight hexagonal faces) has inherent impact absorbing properties as they are a regular representation of the cellular structure of foam (Brennan-Craddock et al. 2012). Netfabb's 'Pyritohedron' lattice cell – a polyhedron composed of 12 pentagonal faces – was chosen due to its similar composition to a 'Kelvin Cell', although it was later noted that the 'Vin Tiles' cell is a more accurate representation.

The parts from i.materialise were both produced in a flexible TPU material with a Shore A hardness of 88. Two proprietary materials, produced by Formlabs, were used with the SLA process: 'Elastic 50A' and 'Flexible Resin', with Shore A hardness of 50 and 80 respectively. The Shore A hardness scale is widely used in the plastics industry to characterise the hardness (or durometer) of soft to medium-soft materials such as vulcanized and natural rubber and TPEs (thermoplastic elastomers). The Shore A durometer scale ranges from 0 to 100, representing how resistant the material is to localised indentation, with the higher the value, the harder the material (Xometry 2023). New Balance use Formlabs' 'Rebound Resin' (with Shore A harness of 86) in the soles of their 990 Sport Triple Cell and FuelCell Echo Triple trainers (Formlabs 2024a). This would also be worthwhile testing, but the company treat this as a specialist material only available in minimum order quantities, so this was not viable.

Table 17: Three additive manufacturing processes used to develop flexible lattice sample blocks.

Laser Sintering (SLS)	Multi Jet Fusion (MJF)	Stereolithography (SLA)
 i.materialise - flexible TPU (now discontinued). Shore A hardness = 88	 i.materialise - 'Rubber-like' TPU. Shore A hardness = 88	 Formlabs - Elastic 50A. Shore A hardness = 50
		 Formlabs - Flexible Resin (now discontinued and superseded by Flexible 80A). Shore A hardness = 80

With the higher Shore A hardness, the i.materialise samples feel physically harder compared to the Formlabs SLA samples, and demonstrate higher resistance to deformation when pressed by hand. This potentially indicates greater performance relating to impact absorption, although the samples were not tested for this. However, the harder material may also pose an issue in terms of comfort if used for hip protection. The hardness of 'soft' hip protector pads was a concern for the earlier female focus group (see 4.2.2) linking to issues of discomfort reported in the literature (see 2.2.3).

Both the i.materialise samples have a coarse surface texture, a characteristic of 3D printing processes from powder substrates. Comparatively, the Formlabs Elastic 50A (the softest of the samples) has a smooth finish akin to silicon. The slightly harder Flexible Resin also has a smooth finish, but as a less supple material has a tactility closer to rigid plastic, although is still very pliable. However, the smooth surface finish of both the SLA samples makes them likely to be more comfortable if worn close to the body compared to the rough texture of the SLS and MJF samples. Although the flexible TPU of the laser sintered part is slightly translucent, the smoother surface of the Elastic 50A SLA material increases the translucency allowing the lattice to be seen more clearly below the flat surface. The pattern created where the lattice meets the outer surfaces also provides an interesting visual detail. The opportunity to reveal the lattice this way provides some exciting potential for the aesthetics of the pad.

Overall, in relation to the softness of the material and smoothness of surface texture, the SLA samples produced on the Formlabs machine show greater promise, in terms of comfort, if scaled to hip protector pad proportions. However, the danger of shearing forces against the skin rule out the suggestion of the material being in direct contact with the hip surface. The improved 'Flexible 80A' resin (introduced in June 2020, superseding the Flexible Resin) is more durable with better tear strength (Formlabs 2024) and shows further promise. It is also translucent, like the Elastic 50A resin, providing opportunities for interesting visual detailing. This material, and its impact absorption qualities are investigated in more detail later (see 5.3.3). In addition to the soft, lightweight, and breathable qualities of flexible lattices, the potential of *thinner* hip protector pads is also an important area of investigation. The demand for discreet hip protectors, that are not bulky, is well evidenced in the earlier research.

As part of the initial concept investigation, flexible 3D printed lattice structures as hip protection are discussed in the Under/Over/Outer focus group, especially in relation to the Hipwear UNDER concept (see 5.2.3.2).

5.2.2 Inflatable surfaces

The issue of discomfort of underwear hip protectors is well reported in the literature (see 2.2.3). Additionally, participants in the female focus group (see 4.2.2) were surprised by the weight and hardness of the pads of the Fall Safe underwear hip protector. To reduce weight, and the hardness or rigidity of pads over the hips, I considered the use of inflatable protective elements as an initial design idea.

In the contextual review, I noted that airbag hip protectors are beginning to be developed by manufacturers such as Active Protective Technologies, Helite, and S-Airbag. However, I hypothesised that the complexity and cost of these products could be a potential barrier to their use. This was later tested through the online survey (see 4.3.4) where barriers to their acceptance were determined as cost (37%, n=146) and on-going maintenance, such as battery charging (24%, n=146) and gas cartridge replacement (31%, n=146). Through analysing the responses by age, the latter two issues were more likely to affect respondents aged 70 and over.

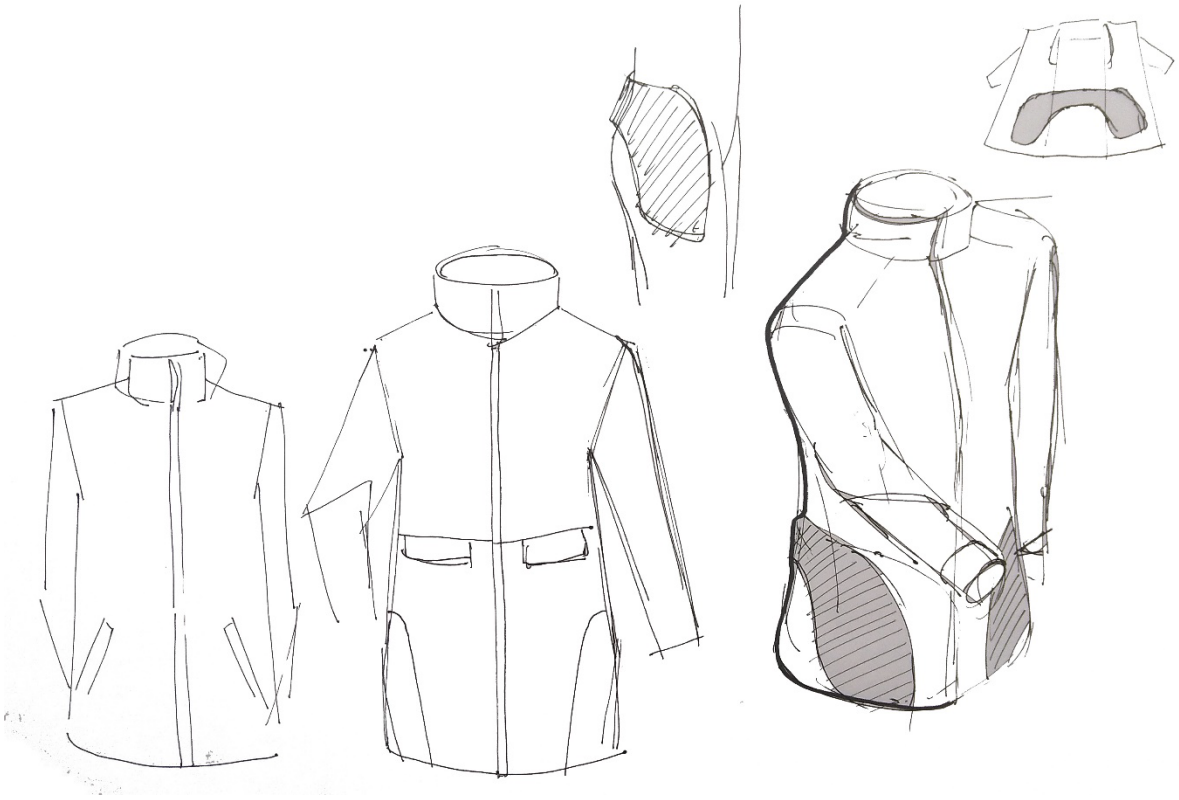


Figure 62: Concept sketches exploring inflatable hip protection integrated into a jacket.

I decided to explore the idea of using inflatable technology in other ways. Initial design concepts consisting of inflatable surfaces integrated into garments were conceived to provide lightweight hip protection to overcome discomfort issues. In this scenario, the hip protector would be worn with layers already inflated. I also began to consider how the design language for hip protectors could be challenged, where issues of aesthetics and discretion are embraced through garments that have a familiarity and reflect active lifestyles. This included the consideration of inflatable padding integrated into a jacket around the hips (see Figure 62), and the notion of an inflatable 'wrap' that could be built into outerwear (see Figure 63). This work engages with similar principles to the Pneu-tex jacket (Cheng 2020), that has integrated airbag protection. However, it is important to note that the work presented here was completed before the Pneu-tex project was published in 2020.

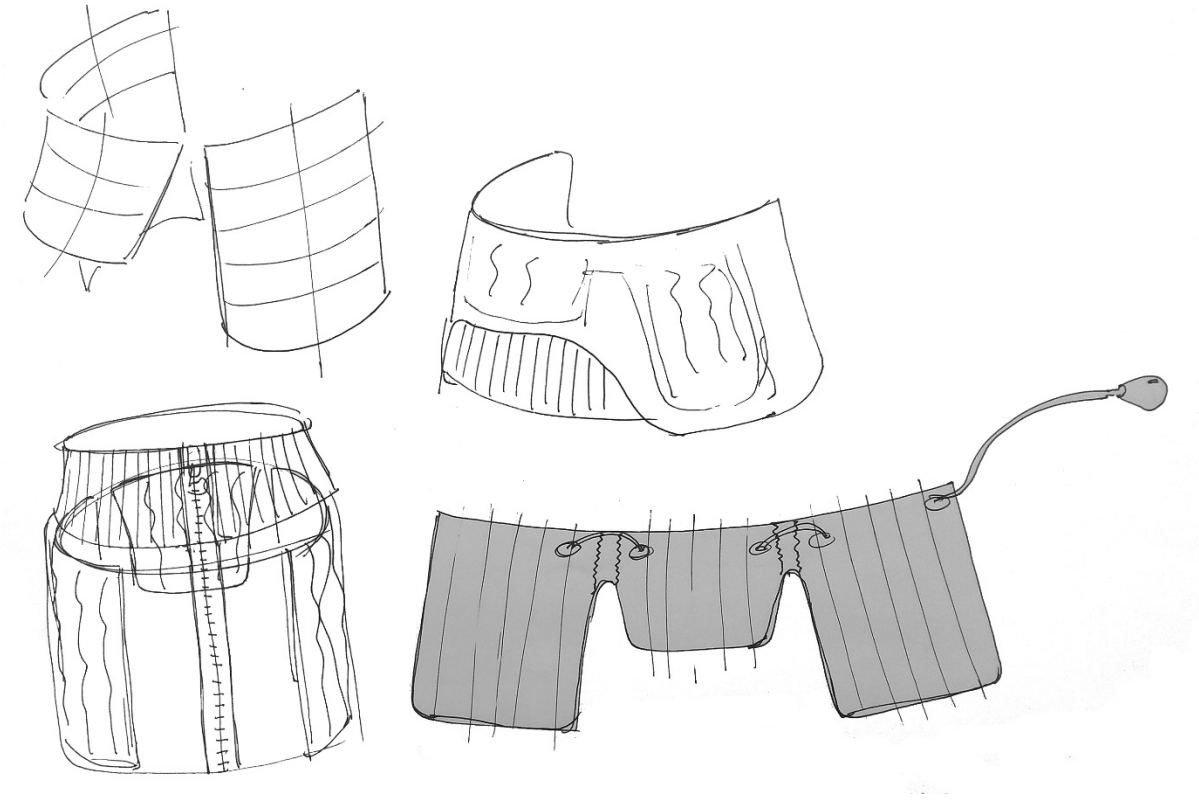


Figure 63: Concept sketches exploring inflatable 'wrap' that could be integrated into outer garments.

Some other potential advantages were also considered early on. In terms of difficulty getting on and off, a deflated garment would be loose and easier to get on and off than a tight fitting garment. It could then be inflated once it was on and in position. With reference to the work of Hall et al. (2017)

and the NuDown jackets, the garment could also provide lightweight thermal insulation. This could be beneficial if inflatable protection was integrated into an outer garment such as a jacket.

5.2.2.1 Airbag hinge test pieces

As discussed in the contextual review (see 2.3.5), Ou et al. (2016) propose a pneumatic hinge mechanism that allows directly encoded, user defined material shape changes, within two dimensional structures. Their 'aeroMorph' technology relies on two sheet materials (they experimented with TPU coated plastic, paper, and fabric) heat sealed together following a predetermined pattern. The geometry of the resulting interconnected air chambers affects the shape the object takes in its inflated form.

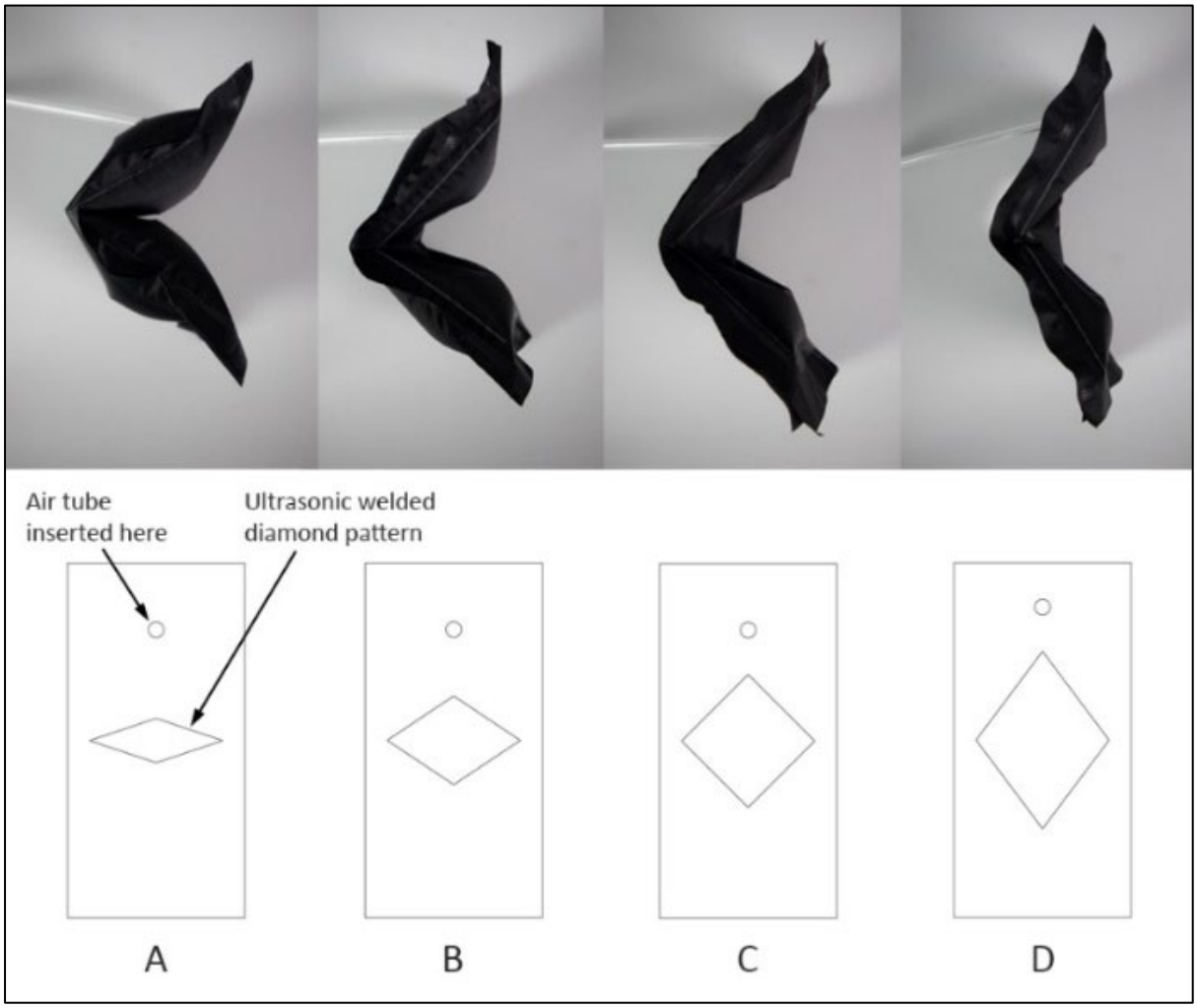


Figure 64: Airbag hinge test pieces showing how the width/height aspect ratio of the diamond controls the hinge angle at full inflation.

The potential for surfaces that could wrap around the shape of the body as they were inflated, but also have inherent impact absorbing properties, provided an exciting starting point for design concepts. This idea underpinned the later focus group discussion (see 5.2.3.4). I began exploring the principles of designing inflatable bending structures through simple airbag hinge mechanisms. This allowed me to experiment with, and understand, the fabrication processes involved.

I recreated the hinge mechanism airbags presented by Ou et al. (2016), experimenting with the width and height aspect ratio of the ultrasonic welded diamond pattern to control the bending angle (See Figure 64). These test pieces were inflated by manually blowing into a connected PVC tube. The greater the height compared to the width of the diamond, the wider the hinge angle produced, represented in a bending calculation generated by Ou et al. (2016). Notably, the space inside the diamond is completely sealed and does not inflate, so the increased height to width ratio also decreases the surface area of the hinge that is inflated, reducing its potential for impact absorption. This is seen in the more inflated appearance of 'A' compared to 'D'.

Figure 65: Airbag hinge test piece 'B' being sealed on the ultrasonic welder.

The process provided proof of principle with the intention of creating repeated hinges across larger fabric surfaces that could be integrated into hip protector garments (as represented in concept sketches in Figure 63). However, these early experiments also allowed me to investigate alternative fabrication methods to the MIT team. For example, to create airtight surfaces, and for their heat sealing methods to work, Ou et al. (2016) bonded a thermoplastic polyurethane (TPU) hot melt film to the surface of the materials they were using. This extra process was avoided by using 2oz PU Coated Nylon, an airtight fabric with good strength and tear resistance (Profabrics 2024). Instead of heat sealing, I used ultrasonic welding, a bonding technique commonly used in garment manufacturing. High frequency vibration and pressure is applied through the two fabric layers creating frictional heat that forms a molten weld zone leading to a stronger bond then heat sealing (Petrie 2015). I used a Sew Systems SSU-015R Ultrasonic Machine (Sew Systems Ltd 2023) with a 5mm wide wheel to ensure an air tight seal. A laser cut card template provided a guide to draw the pattern directly onto the fabric using a white pencil, which was then followed with the rotary wheel on the ultrasonic welder (see Figure 65). This provided a quicker and more efficient sealing technique compared to Ou et al's. (2016) method of manual fabrication. They used a heat sealer that bonds the fabric across a straight fixed length, so had to cut and apply copper tape (that dissipates heat) to cover the areas not to be sealed (air channels) beforehand.

5.2.2.2 Shape-changing inflatable panels

The initial experiments preceded an investigation into shape-changing inflatable surfaces at a larger scale. I began by exploring a panel for one side of a garment that could broadly curve around the hip area as it inflated. The panel had a tapered shape, wider at the top and narrowing towards the bottom, approximating the form explored in the hip belt concept. The diamond width and height aspect ratio from test piece ‘A’ was trialled first as it was hoped that the smaller hinge angle would create a more pronounced curved surface. The notion of the panel wrapping – almost gripping – around the hip was of interest here.

Three variants were developed (see Figure 66) to investigate how the panel would inflate with the hinge centres aligned with the taper direction (E), or aligned vertically (F), and with wider lateral spacing of the hinges (G).

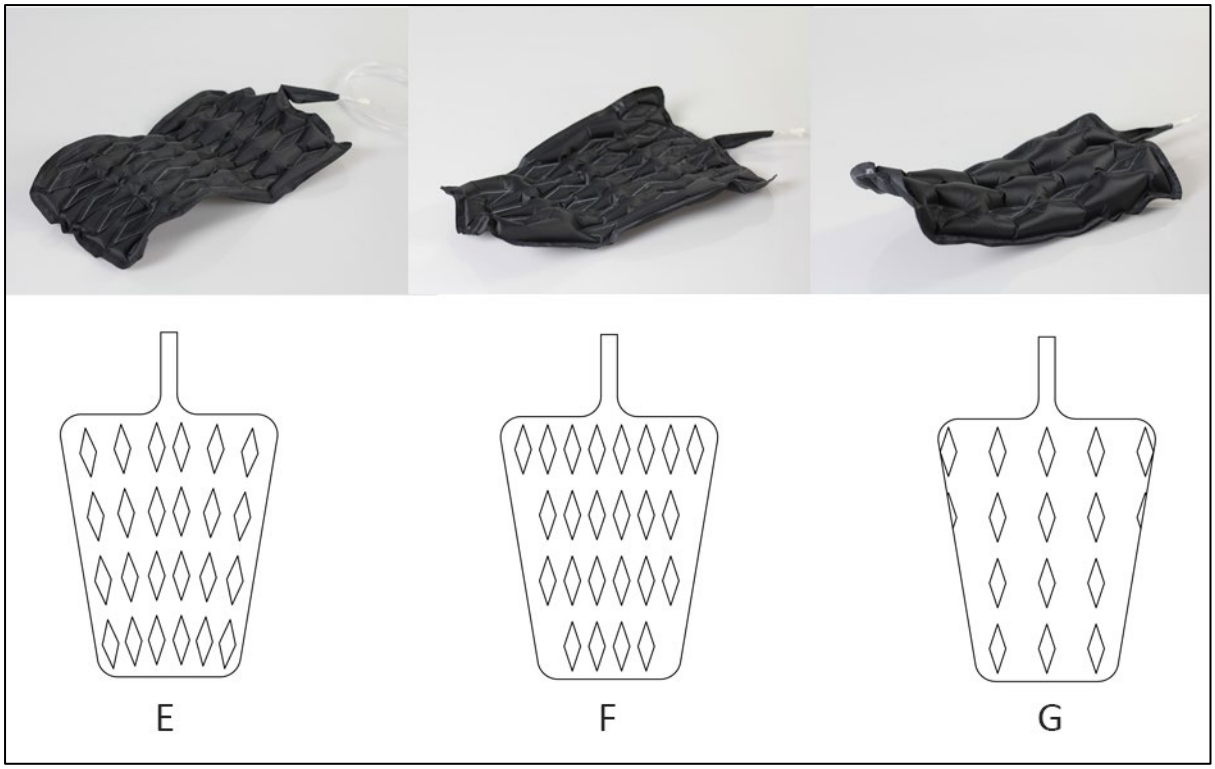


Figure 66: Shape-changing inflatable panel experiments, E, F, and G (patterns and inflated prototypes).

Although all three panels have the same shape when deflated, they take on quite different forms when inflated. The hinge arrangement on ‘E’ caused the panel to form a shallow S-shape in side profile. Evidently, the wider spacing of the hinges towards the top caused the panel to curve (albeit only slightly) as was hoped. However, the hinges towards the bottom of the panel are closer together, reducing the volume that can be inflated in this area. It is the deformation of the fabric around the hinge when inflated that causes the bending motion, so if the fabric has little room to inflate, the curve around the hinge will not occur. This is prominent in ‘F’ where the hinge spacing is consistent across the panel. The inflated form is relatively flat with only the areas around the edges with no hinges prominently bulging. Test piece ‘G’ is much more successful with the panel curving into a clear arch shape. However, this is less prominent at the narrower end where there are only three hinges, and the shape is flatter. The hinge spacing is doubled compared to ‘F’ allowing more volume in the panel to be inflated. The larger pockets of air also look more promising from an impact absorption perspective.

For inflation, I used a small aquarium air pump (max 3W for 45 litre tank) as a low-cost method of providing a continuous flow of air. The pump was connected via a PVC hose pushed through a small opening in the neck of each panel between the bonded fabric. The hose was sealed around the

opening with tape. The pump worked sufficiently to inflate the panels, but I found it was quicker to inflate, and higher pressure could be achieved, by manually blowing through the tube. Once inflated, the neck of the panel could be pinched to keep the air inside.

In stricter test conditions, using a higher pressure air pump, and having means of measuring the internal air pressure, would be important. A way of inflating and sealing the panels in a hip protector garment would also need further development, but at this stage a hand bulb air pump and valve (as used on the NuDown jacket) was considered. However, this would not be an appropriate solution for a user with hand grip strength or dexterity issues, such as arthritis, so other methods, such as a manual blow tube (although this could also be challenging for some people) or small electrical pump, could also be explored.

To develop larger scale and quickly repeatable shape-changing inflatable surfaces, Ou et al. (2016) followed others (Niiyama et al. 2015) by developing a robotic sealing method using a CNC machine. This provides quicker, more versatile, and precise sealing capabilities compared to the ultrasonic welding method that I used.

5.2.2.3 Prototyping an Inflatable wrap garment

This later work was conducted after the focus group to discuss the potential of inflatable hip protection (see 5.2.3.4). For consistency, I have presented it here alongside the earlier experimental work with inflatable surfaces. However, the design development is reflective of the ideas that emerged from the focus group and the relationship between the two will be discussed further later on (see 5.2.4).

Further mock-ups were developed, experimenting with the overall shape of the panel and the scale and arrangement of diamond hinges. This was quickly translated from a single panel to the concept of an inflatable garment that wraps around both hips and the lower back (see Figure 67 and Figure 68). The notion of the inflatable padding protecting other parts of the body was discussed in the focus group. As the inflatable hip panels are connected through the air chambers around the back of the garment, it is also a good opportunity to protect the lower back and coccyx which are also vulnerable to fall injuries.

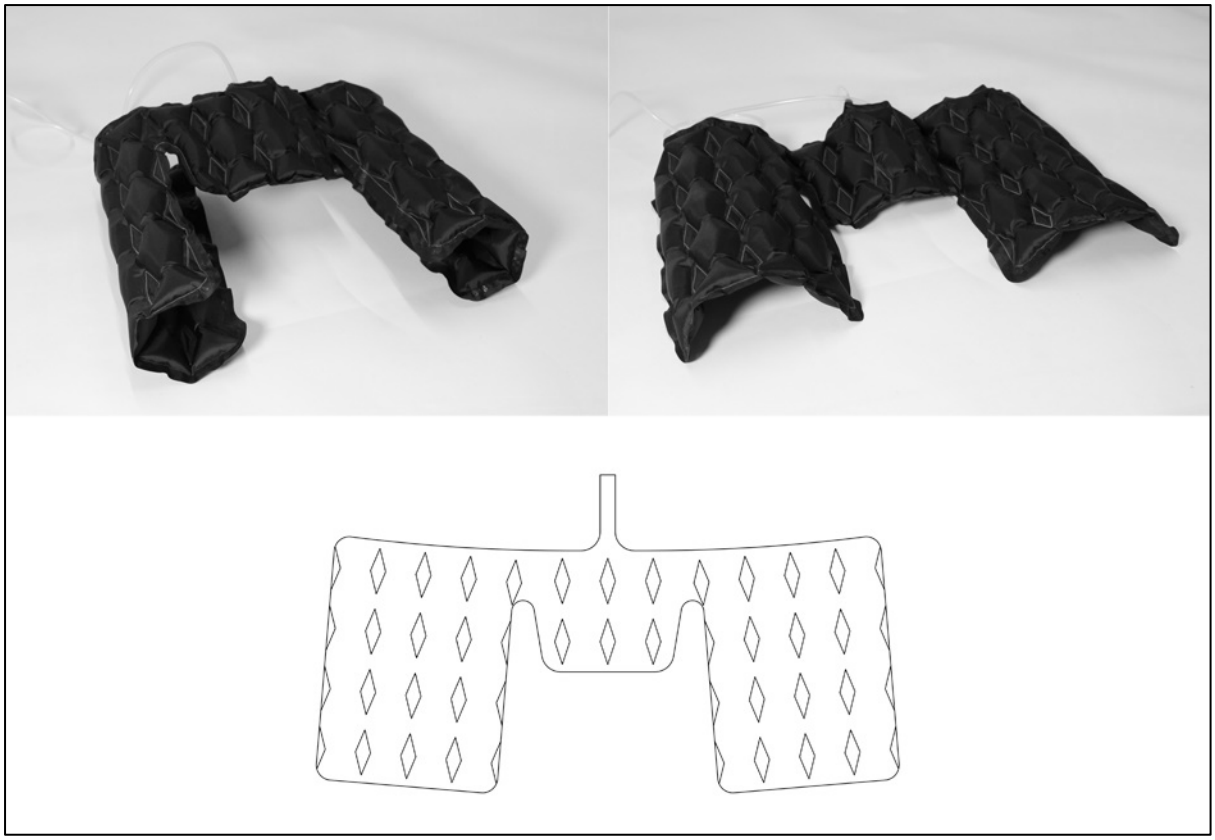


Figure 67: Inflatable wrap pattern and inflated prototype (Left: panels rolled under supporting the weight of the back portion. Right: laid flat showing natural arch shape of panels created through inflation).

Figure 68: Inflatable wrap prototype on a mannequin.

Although the diamond hinge size and spacing used in test piece ‘G’ was applied here, I made the outer shape of the hip panel rectangular, rather than the earlier tapered form. This allows the arch shape to run more consistently through the length of the panel, preventing the flattening and flaring of the shape seen at the narrower end of ‘G’.

In Figure 67, the left-hand image indicates the rigidity of the inflated part as a self-supporting structure. However, the right-hand image shows the natural form the arched panels take when it is inflated. In both instances, the prototype was inflated with the aquarium pump and the air pressure was not measured. However, the images demonstrate that the panel was able to curve to approximate the shape around the waist, hip, and upper thigh (see Figure 68), but still maintain some flexibility of movement. It is an important consideration that the inflated garment is not too rigid and restrictive to move in.

Figure 69: Inflatable panels integrated with a wrap style garment produced by DM Orthotics.

I discussed the concept of a wrap style garment that could be worn independently or integrated into the lower portion of a long jacket, with participants in the focus group (see 5.2.3.4). The idea was later developed in discussion with DM Orthotics who produced a mock-up for a wrap style garment which would hold the inflatable wrap prototype already developed (see Figure 69). This provided a way for me to evaluate the wearability and feel of the concept at this stage.

The padded sensation of the air-filled chambers around the body felt comfortable to wear. This overcomes the issue reported by some hip protector wearers of hard pads digging into the hips (see 2.2.3). However, when not even fully inflated, the garment was restrictive to walk around and sit down in. Neither was it is easy to put on as the zip started at the bottom of the wrap and needed to be pulled up to the waist. It was designed this way to simulate the lower portion of a jacket and would also be appropriate if the wrap was integrated into a jacket. As an independent garment, it would be easier to pull the wrap around the waist first (and perhaps hold it there with a popper or Velcro fixing), then pull the zip downwards. Notably, all these actions are also subject to the users hand strength, dexterity, and general mobility.

In terms of impact absorption, the specification for the panels relating to their inflated thickness and internal air pressure were yet to be investigated at this early concept stage. However, with the panel fully inflated (both with the aquarium pump and later by manual inflation), I was still able to press down over the hip area and flatten the panel to the skin. The air simply moved into the adjacent chambers. Thinner inflated panels are more discrete but would inevitably need to be inflated to a higher pressure to avoid collapsing on impact and the wearer's hip joint contacting the floor surface below. Higher pressure inflation may impact on the flexibility of movement when wearing the garment, which perhaps could be overcome if the protective area was smaller and localised only over the greater trochanter. However, manually inflating the garment to high pressure could be difficult for the user and invite operator error if the system does not feedback when the optimum air pressure is reached.

When a fall occurs, the outside compression on the inflated panel, sandwiched between the wearer's body and the floor, will rapidly increase the air pressure inside the pad. The risk of the inflatable panel rupturing in this circumstance must also be considered. A pressure release valve could be introduced to prevent this from happening and assist the deceleration of the user towards the floor. In this circumstance, lower pressure inflated panels could be a preferrable approach, as they require less work to inflate and their pliability inside a garment would make it easier to move around in. Indeed, shape-changing inflatables that curve around the body could be less practical than a series of air chambers that are held in place around the hips by the garment itself. However, the air chambers

would need to be independent of one another so when they do meet impact forces, the air cannot simply move to another part of the garment.

As with the design of all hip protectors, the technical viability of an inflatable solution is of less value if the look and feel of the garment does not appeal to potential users. This initial concept investigation sought to challenge current forms of hip protection and explore new garment types that could embody a more sensitive visual design language. Inflatable hip protection could be disguised within the padded layers of a well designed jacket, for example. This speculative concept is one of the ideas brought to the Under/Over/Outer focus group, below.

5.2.3 Under/Over/Outer focus group

The themes established through the early research underpinned the development of three speculative design ideas and opportunities for innovation in hip protector design. These provided a foundation to consider different contexts of how the garment could be worn, responding to earlier investigation into the advantages and disadvantages of hip protectors worn as underwear or over clothing. The concepts were:

- Hipwear UNDER – a low profile hip protector belt worn separately on top of underwear but under clothing.
- Hipwear OVER – hip protection integrated into a garment worn over clothes, with pockets for phone, purse, keys, etc.
- Hipwear OUTER – a three-quarter length jacket with integrated inflatable hip protection.

5.2.3.1 Methodology

The focus group was with four of the female participants who took part in the earlier focus group. For this reason, a pre-participation meeting was not necessary as they were already familiar with the research project. The focus group took place at Carnon Downs village hall, shortly after the iCareiMove exercise and balance class that happened in the same building. This was to make attendance to the focus group as convenient as possible for the participants who were also taking part in the weekly exercise classes. The session lasted 1 hour and consisted of a re-cap on the

discussion at the last focus group, a presentation on the format and aims for the session, and the activity to explore the three design concepts.

The focus group was documented using a Zoom H4n portable audio recorder to afford a higher quality recording compared to earlier focus group recordings. I made a back-up recording using Audacity audio software (Audacity 2024) on a laptop. A video recording was also made using a Canon 5D MkII DSLR camera mounted on a tripod in the corner of the room. I chose this camera for convenience so both video and still images could be captured on the day.

Discussion focused on the three concepts presented through printed visual boards and material samples. I presented each board individually and planned for about 15 minutes of discussion for each concept. In addition to the boards, I also presented material samples that provided a tactile reference to the concepts being discussed. The participants were asked to identify strengths and weaknesses with each concept which I jotted down onto Post-It notes and placed next to the board. The discussion also expanded, and the participants considered further design opportunities, asking, for example, “could it do…?” or “it would be good if it included…”. Although this approach reflects a SWOT analysis, no ‘threats’ were specifically identified by the participants as these were conflated with perceived weaknesses. Their insights helped to evolve the concepts during the workshop, challenging preconceived notions of what hip protection could be. In particular, this engaged with the research question by exploring the performance requirements of the garment beyond reducing the risk of hip fractures, and how sociocultural and lifestyle aspirations can be represented through its look and feel.

As with earlier focus groups and interviews, the written transcript (see Appendix M) provided the main source of data for analysis. In addition to the Post-It notes, I carefully reviewed the transcript to draw out the perceived strengths and weaknesses of the concepts, and the opportunities for further development. This analysis contributed to the growing criteria for the development of new types of hip protection. The exercise also provided a useful set of ideas to explore and develop through the online survey.

5.2.3.2 Hipwear UNDER discussion

The Hipwear UNDER concept (see Figure 70) was the first to be discussed. This was the low profile hip protector belt worn under clothing but on top of underwear. In addition to the visual presentation board, the participants were also shown the prototype produced by DM Orthotics (see

Figure 60), and the Formlabs Elastic 50A SLA 3D printed flexible lattice sample to indicate a potential protective pad material. This design was particularly informed by the feedback provided by the same group of participants during the earlier focus group. The key observations noted in Post-Its are shown in Table 18.

Table 18: Strengths, weaknesses, and design opportunities noted for the Hipwear UNDER concept.

Strengths	**Weaknesses**	**Opportunities**
Style better for women	Prototype is bulky	Higher waist band for comfort
Lattice material is breathable	Uncomfortable across the tummy	Lace detailing not necessary if adds to expense
		Underwear worn on top
		Front closure (e.g., Velcro) for ease of use
		Used in sports context

The way this concept was separated from underwear was seen as a better design for women to wear. This was mainly due to ease of using the toilet. One participant noted, “In style, it's better for females, definitely, than trying to pull a pair of pants up”. Although the illustration shows the garment worn over underwear, the participants showed a preference to wearing pants on top instead. This was so it would be easier to pull the underwear up or down, but it would also help to stabilise the pad position. Although it was deemed helpful that the hip protector could stay in place when using the toilet, the group felt that it would be better to have a front closure, such as Velcro, to make it easier when first putting the garment on or taking it off at the end of the day. When reviewing the DM Orthotics sample, one participant commented that she would struggle to “get both legs up high enough” to step into the garment.

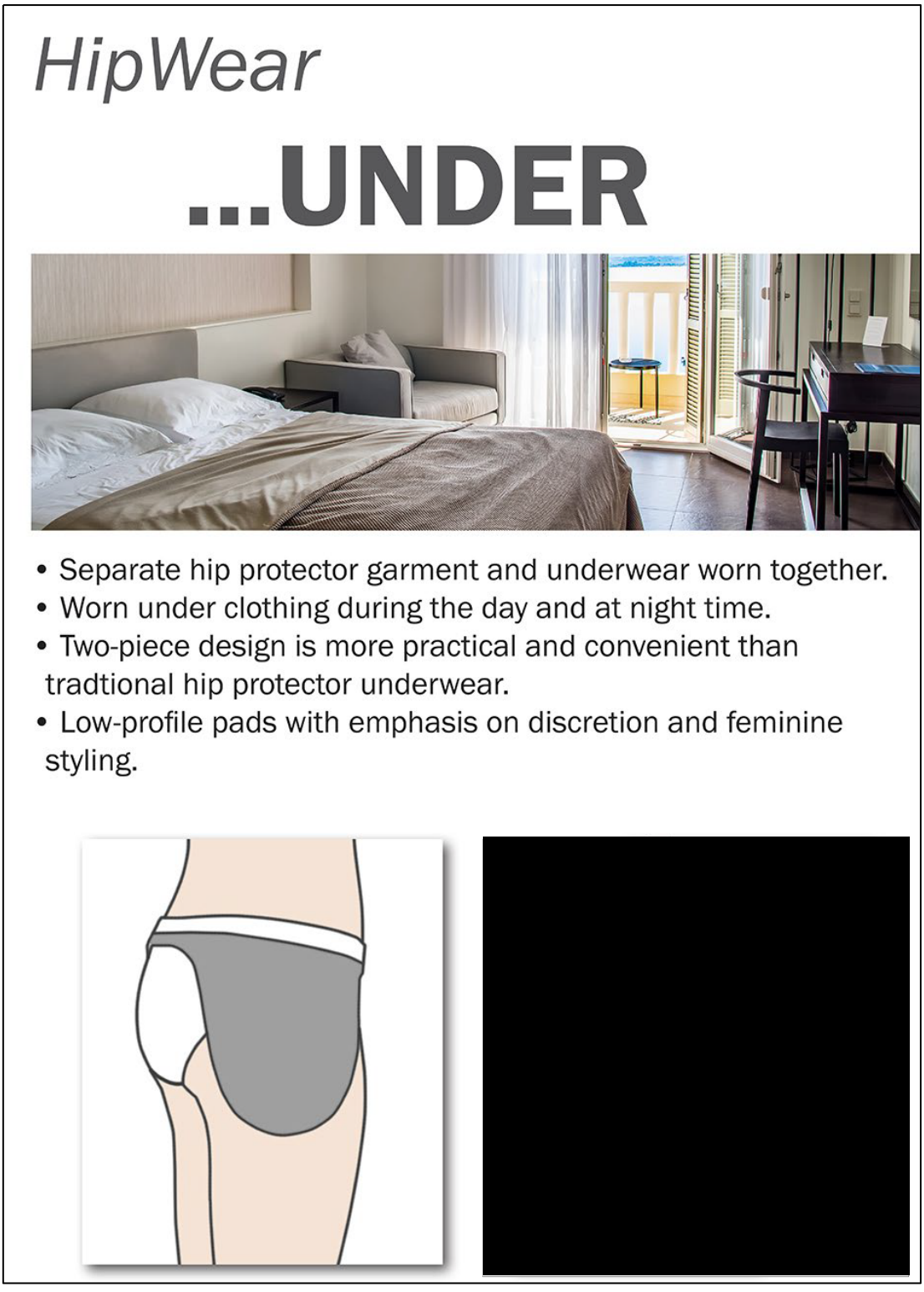


Figure 70: Hipwear UNDER concept visual presentation board.

Concern was expressed over the position of the belt across the lower abdomen and how that could become uncomfortable. One woman described pressure across the tummy as “quite restrictive” and noted a preference for the belt to be worn higher on the waist. This point was agreed by the other participants. The need for the garment to be tight enough to keep the pads in place further highlights this as a potential problem. A higher waisted garment, and a wider waistband to spread the pressure, is an opportunity for development.

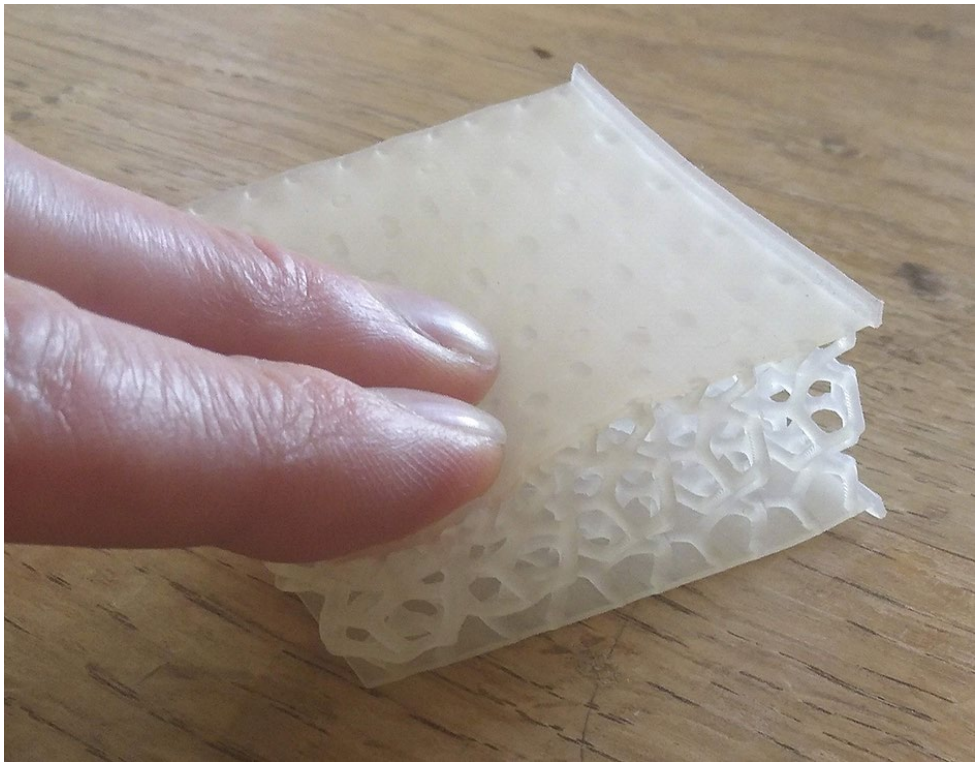


Figure 71: Formlabs Elastic 50A SLA 3D printed flexible lattice sample (50x50x20mm) shown to focus group participants.

The prototype garment was perceived to be too bulky. A participant commented, “I don't think, if I was going out anywhere, I would wear anything that protruded”. This echoes earlier concerns about the discretion of hip protectors worn under clothes. However, the participants were receptive to the 3D printed flexible lattice material (see Figure 71) to provide impact absorption, noting it’s silicon feel, and breathability of the lattice. One of the women commented, “that’s lovely […] and easily cleaned, I imagine”. The softness of this sample – and perceived limitation to absorb impact – was noted, however: “It does contract very, very easily. I don't have to put much force on it”. The potential of lattices in different materials are explored later, including how they could be designed to be thinner than current hip protector pads (see 5.3.3).

The visual appearance of the concept, especially the proposed lace detailing, was also met with mixed opinions. One of the participants valued the suggested femininity, noting that her older age was no barrier to wanting to feel feminine. However, another felt it wasn't a high priority, adding, "I wouldn't like the cost of it to increase enormously just to put lace over it […] it's such a practical thing, it doesn't need to be pretty". On this point, the idea of it having a sporty aesthetic was noted by two of the participants. Different perspectives on the visual appearance are to be expected with differing tastes. This early interaction was indicative of a demand for different visual styles of protective garments which was later explored in the online survey (see 4.3.5). However, the focus group feedback pre-empted the interest in both sporty and casual, and sophisticated and elegant hip protector styles prioritised in the survey data.

5.2.3.3 Hipwear OVER discussion

The Hipwear OVER concept (see Figure 72) was conveyed through the visual presentation board only, as there was no prototyping or materials investigation at that stage. The concept relates to a garment that can be worn visibly over clothing, with integrated hip protection, but could also provide other functionality such as a pocket for a phone, keys, or purse. The images used were examples of existing types of pocket style garments worn as a belt found on the image sharing website, Pinterest. The key responses from the review are presented in Table 19.

Table 19: Strengths, weaknesses, and design opportunities noted for the Hipwear OVER concept.

Strengths	**Weaknesses**	**Opportunities**
Easier to put on if going out suddenly	Want to look 'normal'. This would seem out of place	Include fall detection monitoring to alert someone if you fell
	'Advertises' ageing	
	Need several different styles to go with what you are wearing	
	Could get caught on crutches	
	Need to remember to put on	

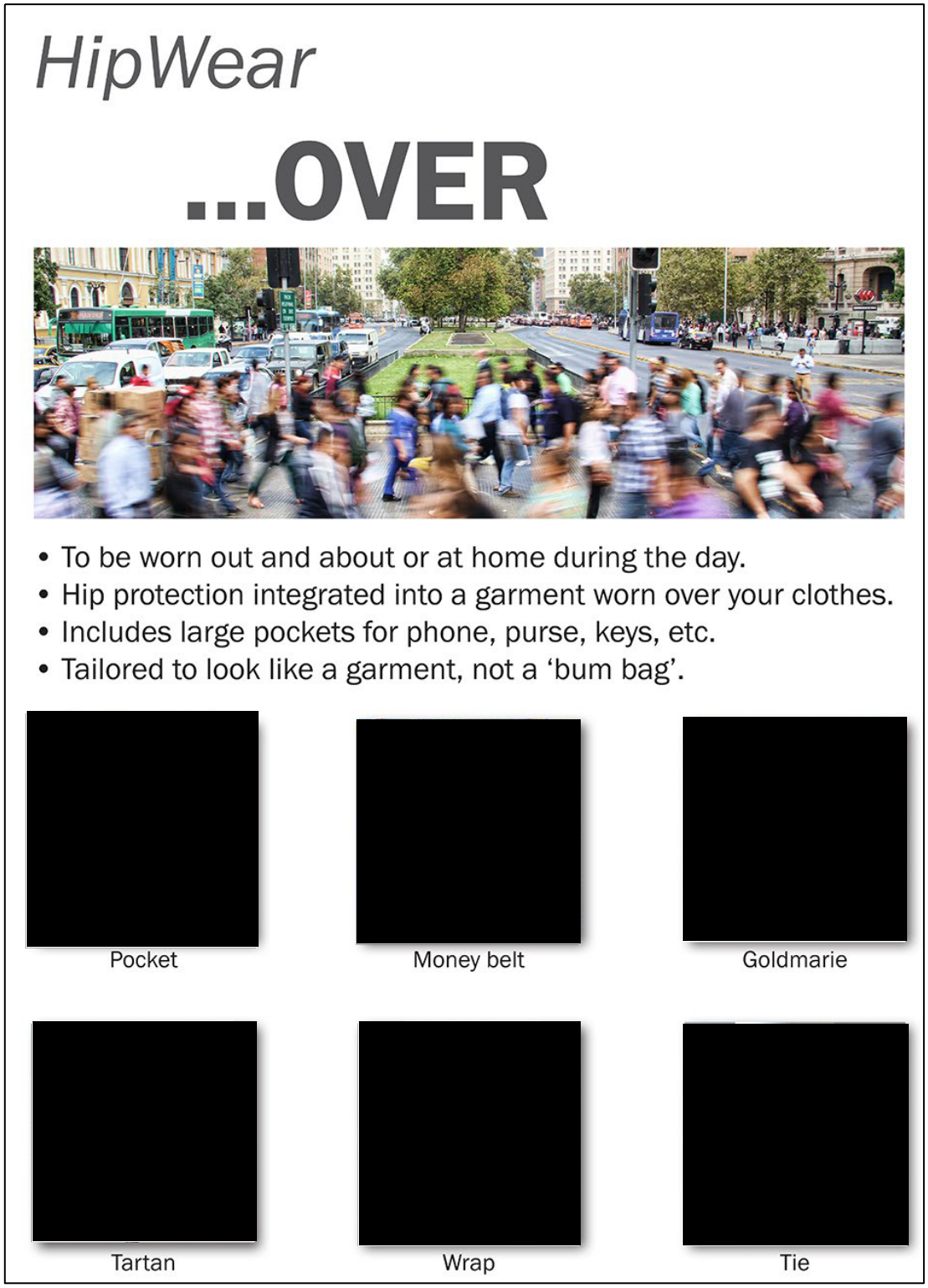


Figure 72: Hipwear OVER concept visual presentation board.

The overall feedback was much more negative compared to the UNDER concept. None of the participants were keen on wearing a garment that was visible over their clothing. One participant originally indicated she would wear the 'Tie' design, but later rescinded after another described it as looking, "like a bandage". The responses resonated particularly with Topo and Iltanen-Tahkavuori's (2010) framework of patient clothing along the dimension of normality to otherness. Not looking normal, seeming out of place, and 'advertising' ageing, were all aspects of otherness expressed by the participants. For example, one participant commented, "it's another advertisement that I am old and I'm decrepit […] I don't want to advertise another problem when it hasn't happened".

From a practical perspective, the need for different styles to match different outfits, and fear that the garment could get caught on crutches (for one participant in particular) were also perceived weaknesses. One of the women likened the concept to someone wearing a backpack, unaware of how the protrusion can knock into people. Although the convenience of putting the belt on, for example, before going shopping, was recognised, the participants also noted how easy it would be to forget to do so: "You just won't remember to do it. You might think you will the first few times, but after that, it would be something that's a waste of money, because people wouldn't use it."

A discussion about wearable safety alarms prompted the idea of a fall detection and automatic alert system integrated into the Hipwear OVER concept. This is already a proven technology as Hip Impact Protection offer their Fall Safe underwear hip protectors with the Fall Safe Assist product (Hip Impact Protection 2024). The participants were much more positive about this conceptually but none of them saw this as motivating enough to wear a visible hip protector over their clothing.

5.2.3.4 Hipwear OUTER discussion

The final concept reviewed was Hipwear OUTER (see Figure 73). This concept was derived from the initial design practice exploring the potential of inflatable surfaces for impact absorption (see 5.2.2). The idea relates to a three-quarter length jacket with inflatable protection integrated into the lower portion around the hips. The visual presentation board uses a ski jacket with a snow skirt to illustrate how the garment might be constructed, and details from the NuDown jacket that uses air pockets for insulation (NuDown 2018). I also demonstrated one of the shape-changing inflatable panels that had been developed. The key responses from the review are shown below in Table 20.

Table 20: Strengths, weaknesses, and design opportunities noted for the Hipwear OUTER concept.

Strengths	Weaknesses	Opportunities
Sporty looking	Cost	Inflatable lining as a separate garment that could fit under any long jacket
Unisex	Seasonal, only worn during colder months	Inflatable padding in other areas
Compression	Could be bulky	
	Additional hassle to use with incontinence products	
	Restrictiveness, e.g., difficulty sitting	
	Embarrassment at revealing inflatable lining when removing the jacket	

Like the Hipwear UNDER concept, this idea was met with opposing views. Two of the participants were more receptive to the jacket concept. One commented, “I think the idea of it blowing up, could be anywhere in the jacket”, noting the opportunity for protecting other parts of the body. Another said, “I would want it for the compression, for protection and feel”, alluding to the expected proprioceptive qualities I had suggested. However, issues relating to the practicality of the garment were also raised. One of the women stated, “I wouldn't walk around with an area blown up around me cause I'm trying to lose weight, and that adds it back on”, perceiving the inflated part to look bulky. Another participant suggested, “It would be incredibly expensive and […] only in winter, when it’s very cold”, noting the cost would outweigh the benefit if it can’t be used all year round.

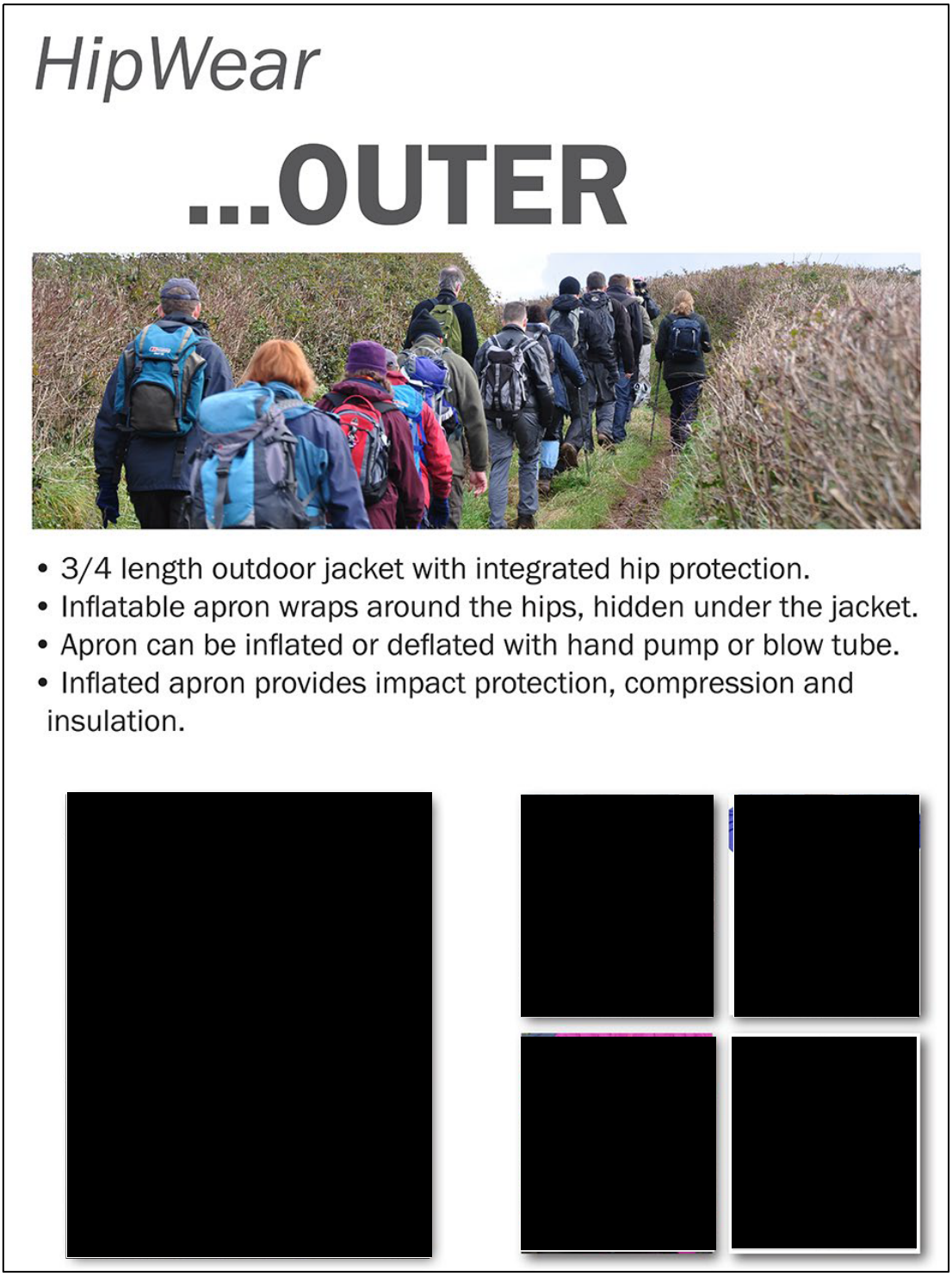


Figure 73: Hipwear OUTER concept visual presentation board.

I prompted the participants to consider how the issue of seasonality could be overcome. The notion of making the jacket and inflatable wrap independent of each other was suggested: “Another garment which is inflated all around instead of two little pads, like a little crinoline underneath your skirt”. This initiated a discussion on how a separate inflatable lining could be fitted under any longer length jacket, reducing the cost and making it more versatile. The idea prompted the development of the inflatable wrap garment discussed earlier (see 5.2.2.3).

Other aspects of the inflatable concept, however, were also perceived as problematic. It was noted that the inflated wrap around the waist and hips could be restrictive and make it particularly difficult to sit down. This was indeed a major issue later observed through the inflatable surfaces prototyping. The manual inflation was also seen as an extra hassle, with one participant noting that using incontinence products would be enough to deal with on its own. Like the Hipwear OVER concept, there were also concerns about the garment signalling ‘otherness’. One woman considered a scenario of having a coffee in town and needing to take the jacket off: “I'd be happy to walk around with that, but then when I got to the coffee shop […] I don't want to take my coat off and show everybody that I've got this”.

Finally, the potential to link the garment to sports or leisurewear was raised again. A participant noted that if, “it’s aimed at ramblers, where you are likely to fall, […] you will always keep it inflated. I could see people being attracted to it because […] it has the sporty connotation”. There was also a perception that the design would be more forgiving for different body shapes and sizes, and that the concept could be worn be women or men.

5.2.4 Reflection

The initial concept investigation provided a useful starting point for the exploration of new types of hip protector garments. This early work engaged with speculative concepts that responded to user needs determined through research *into* design. The UNDER, OVER, and OUTER Hipwear ideas evolved from this investigation, and the focus group allowed a pause in the development process where these ideas could be evaluated through the eyes of potential users. This was a critical part of Action Research, providing an opportunity to reflect on what had been learnt, and establish priorities for onward design development.

The focus group feedback reinforced the issue that hip protectors need to be discreet and the visual language of hip protection should express social-cultural norms. The Hip Belt, informing the UNDER

concept, was designed to be hidden under clothes and take visual cues from female underwear. However, the perceived bulkiness of the garment was still off-putting. Similarly, the notion of disguising inflatable padding in a jacket is all well and good, until it needs to be removed in public, revealing to others the protection surrounding its vulnerable wearer. For the Hipwear OVER concept, not looking normal, seeming out of place, and 'advertising' ageing, were all aspects of 'otherness' expressed by the focus group participants.

Reflecting on the conceptual framework, the cultural negotiation of the meanings expressed by hip protectors is context dependent. The appeal of a sporty aesthetic was raised again in both the Hipwear UNDER and OUTER discussions. This is clearly an area to pursue through further design development, where the visual characteristics of the garment align with the context of exercise and other physical activity. Although the focus group participants were opposed to the OVER concept, none of the design examples presented had a sporty aesthetic, instead conveying a look of casual everyday wear. However, a visible hip protector garment designed to look like activewear has a more intentional context of use, positioning the user as someone ready for movement and physical activity. This may be a more acceptable approach, although the online survey indicates that the women prepared to wear a visible hip protector tend to be younger (56% of the aged 59 and under group).

The Hipwear UNDER concept was the most well received by the focus group participants. The hidden nature of the garment was an obvious advantage to this group. Further opportunities will be explored relating to the garment positioning (i.e., not tight across the lower abdomen) and the potential advantages of underwear worn over the pads, rather than underneath them. The potential for flexible 3D printed lattice structures for impact absorption is another significant area for development, focusing on integration into a slimmer hip pad design.

Finally, although the inflatable surfaces had the potential to offer good energy absorbing properties, the viability of the shape-changing concept was doubtful. The perceived bulkiness, cost and hassle were also issues raised in the focus group. Further development and prototyping of this concept was also disrupted due to the Covid-19 pandemic.

The research *for* and *through* design presented in this section bridges the junction between the 'define' and 'develop' phases of the project. The ideas consolidated here were later scaffolded by the findings from the online survey, focusing the onward development of design concepts. In particular, the notion of hip protection integrated into garments worn on the upper body were explored further.

5.3 Developing the hip vest design concept

Building on the initial concept investigation, I continued to explore ways of innovating across the function, meaning and context of hip protectors. 'Function' in terms of how hip protection is worn, 'meaning' relating to the semanticity of hip protection, and 'context' in terms of who uses hip protection, where and when. By considering different garment types that could accommodate hip protection, new opportunities emerged for products that have a familiarity, and align, aesthetically and ideologically, with clothing types understood and valued by the user. The online survey results demonstrated the demand for hip protection across a broad age range serving different contexts and scenarios of use.

Although the focus group feedback towards a hip protector worn visibly over clothing (See 5.2.3.3) indicated a lack of enthusiasm for this concept, 28% (n=68) of respondents in the online survey said they would wear a style of hip protector that was visible over their clothes if they liked its appearance. Further design development looked at ways of creating a more acceptable aesthetic by focusing on the visual detailing of the protective pads themselves. In the contextual review, I discussed Modeclix (see 2.3.4), a recyclable 3D printed textile (Modeclix 2024), and was keen to explore the potential for a more holistic integration between the garment and hip padding through 3D printing technologies. Inspired by the Japanese ō-yoroi style armour (see Figure 18 in section 2.3.3), this emerged through the development of 3D printed protective tiled surfaces (see Figure 74).

The concept relied on rigid tiles on a flexible base layer that could be backed with an energy absorbing foam. This would mirror the approach of hard-shell hip protectors, made from rigid plastic with a foam lining, that have energy shunting properties to deflect the impact energy away from the greater trochanter to the surrounding soft tissue (see 2.2.2). The principle of shingling (Watkins 1995), where the tiles overlap, was adopted to help spread impact forces. The visual development and prototyping of the protective tile concept are presented in Appendix N.

Figure 74: Sample of EVA foam mounted 3D printed protective tiles on flexible base layer (FDM 3D print using TPU material).

The protective tile concept development occurred alongside further exploration into a hip protector garment worn on the upper body. The notion of a T-shirt or vest, where padding over the hips could be integrated into the lower portion of the garment, started to emerge. Here, the padded element could be tucked into clothing and underwear, or potentially worn visibly outside trousers, for example. The ubiquity of this garment type was seen as an immediate advantage, alongside overcoming concerns relating to padded belt designs such as pressure on the lower abdomen, or the potential for a belt to twist out of position. The value of a base layer, as part of a clothing 'layering system' for active-agers, is also demonstrated through McCann's (2015) 'Design for ageing well' project.

As the design development continued, the 'hip vest' concept became the dominant idea to pursue. This was because the versatility of the garment lends itself to a variety of different styles and contexts that would appeal to different user needs (e.g., feminine camisole or sporty vest). However, the belt concept remained relatively limited in this respect. The opportunity for 3D printed protective tiles is worth exploring further. However, the earlier investigation into flexible 3D printed lattices ultimately aligned better with the hip vest concept as the protective element. The process and rationale for this development is presented below.

5.3.1 Hip T-shirt or vest?

With hip protection integrated into the lower part of a garment worn on the upper body, the direct relationship with underwear, and connotations of specialist underwear discussed earlier (see 4.5), is removed. This not only fosters a different meaning to the garment, but it could also help to accommodate incontinence products more easily for those who need to use them. A vest garment could be stepped into and pulled up the body or pulled over one's head and shoulders. This provides more versatility for putting on or taking off the hip protection compared to underwear style garments. This aligns with design criteria established earlier (see 4.5) and provided the starting point for ideation.

5.3.1.1 Initial sketches and modelling

I initially explored the concept through sketches (see Figure 75), at this stage simply visualising the shape of the garment whilst speculating on what the protective area over the hips would consist of. The potential for integrating flexible 3D printed lattices and 3D printed protective tiles were naturally considered, alongside laminating foam (such as Poron XRD) between layers of the garment fabric, as this is a technique already adopted in protective sportswear (see Figure 19 in section 2.3.3). Initial sketches considered a long-sleeved t-shirt akin to a thermal base layer. Although only appropriate for colder climates, both activewear and underwear contexts are reflected through this garment type.

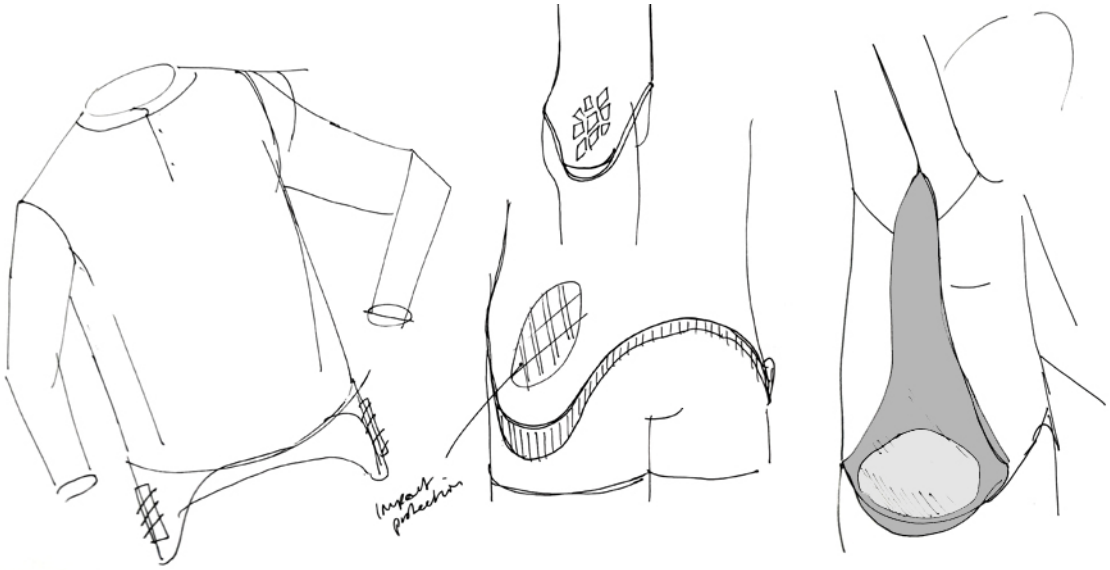


Figure 75: Sketches exploring a shirt with hip protection integrated into the lower portion.

Alongside the sketches, it was important to develop a physical mock-up as proof of concept as early as possible. I developed a crude prototype (see Figure 76) by sewing a calico section approximating the shape of the hip pads to the bottom of an existing base layer shirt. The profile for the hip pad section was derived from the earlier hip belt investigation (see 5.2.1.1) and adjusted to fit my waist and hips.

Figure 76: Hip shirt mock-up detail.

The mock-up was useful to demonstrate how an area covering only the hips could be extended down below the bottom edge of the shirt. The calico panels hung over the hips but could also be hidden by tucking into the trousers. However, the lack of stretch in calico fabric meant that the panels did not sit firmly over the hips but hung loosely at the sides. This would need to be addressed to ensure a secure location for the hip pads. This mock-up did not include any padding, so it was not possible to evaluate the look and feel with a layer of impact absorbing material.

To help visualise potential hip pad details, I took inspiration from the international sporting goods trade fair, ISPO 2019, discussed in the contextual review (see 2.3.1). Using Adobe PhotoShop, I created digital montages of the hip shirt side panel showing the portion under the arm that extends down to the hip pad (see Figure 77). Only a portion of the front and back panels of the hip vest are illustrated here. The colours and fabric textures were applied from images of the Scott USA Airflex back protection and Komperdell's Hoody Shirt. Both sportswear examples have integrated impact absorbing padding with a thickness of around 20-25mm, comparable to the pads in the Fall Safe underwear hip protector, so are useful precedents when re-thinking hip protection. The outcome

was not intended as a design proposal but a means of exploring the potential of a sportswear aesthetic related to the hip shirt concept.

Figure 77: Digital montage of hip pad area with reference to existing protective sportswear. Scott USA Airflex (left) and Komperdell Hoody Shirt (right).

The digital montages demonstrate the opportunity for a sporty aesthetic and the potential for two-tone colour options between the hip pad panel extending under the arm, and the rest of the garment. This detail is also referred to in the right-hand sketch (shaded grey) shown earlier in Figure 75. The window revealing the padding underneath is a detail that is explored later. This work represents a starting point when considering the visual detailing of the hip shirt concept in relation to sportswear. However, further development to establish a simple, feminine, and understated design language is also investigated later.

5.3.1.2 Prototyping a hip T-shirt

The initial exploration of the hip shirt concept preceded the development of more refined prototypes. This included some experimentation laminating 5mm thick neoprene between two layers of Lycra (see Figure 78) to simulate the laminated protective foam padding used in garments like Canterbury and Kooga protective shirts (see 2.3.3). Protex's HiP padded belt hip protector uses 6mm thick Poron XRD foam, so this could easily be translated as a laminated area on the hip T-shirt to

provide a comparable level of protection. IGLO Heavy Polyester Lycra was used for these test pieces, and later garment prototyping, as a material commonly applied to sportswear (Friedmans 2024).

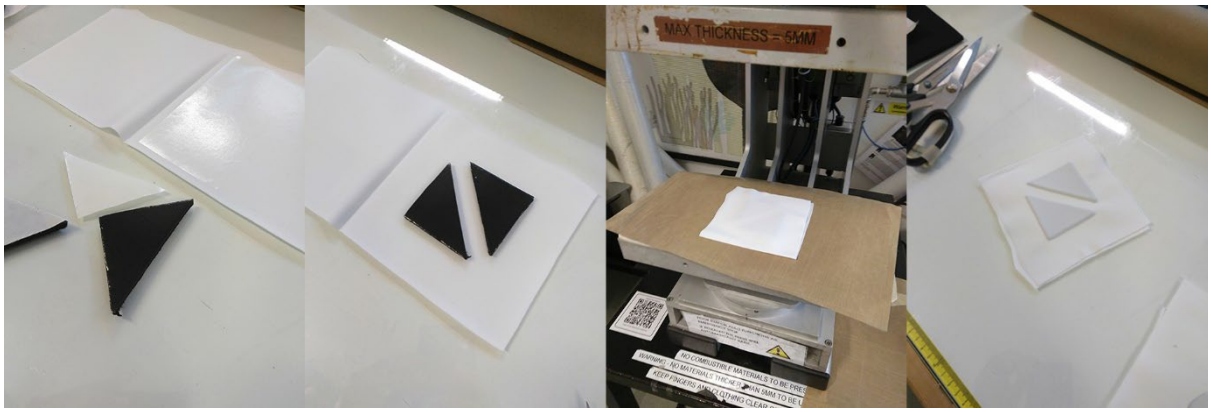


Figure 78: Experimentation laminating 5mm thick neoprene between two layers of Lycra.

Understanding the laminating process provided insight into how this could be applied on a larger scale with a prototype garment. In the sample shown in Figure 78, the channel between the two triangular neoprene pads created a fold line, so I considered how this could be used to control the fit of the padding around the hips.

The hip T-shirt design became more refined using the 3D fashion design software, CLO, in which virtual, true-to life garment visualisations can be created (CLO 2024). This allowed me to visualise the assembled garment, but also establish the flat pattern detailing required for construction. A Raglan sleeve design was adopted as it's a style synonymous with sportswear. The diagonal seam, where the arms extend up to the neck, provides a greater range of arm movement compared to traditional T-shirts, offering more comfort and mobility (Ramsha 2023). The first iteration of the hip T-shirt (see Figure 79) was developed for a male body, so I was able to directly evaluate the wearability of a physical prototype.

For consistency, IGLO Heavy Polyester Lycra and neoprene were used, corresponding to the earlier laminated test pieces. I constructed the garment using adhesive bonded seams (see Figure 80, left), a method common to the sportswear and apparel industry and a more reliable method to sewing with respect to seam strength (Seram and Nandasiri 2015). The garment side panels are wider at the hips to accommodate the region of protective padding but taper to the underarm to meet the junction where the sleeves are joined. The design of the laminated padded area emerged in response to the shape of the garment. The padding covers the whole area where the garment comes down at each

side to protect as much of the hip and surrounding region as possible. The four narrow channels running through the padding provide flexibility to wrap around the shape of the hip more easily.

Figure 79: Hip T-shirt renders using CLO software. Circled detail visualising laminated foam pad area.

However, the central panel alone meets the recommended dimensions for hip coverage (Minns et al. 2007). The channels are linked with small tabs so the neoprene can be laser cut in one piece and the positioning of the five individual components not disrupted during construction (see Figure 80, right). They also create some visual interest with the channel direction following the tapered shape of the side panel up to the underarm. The neoprene padding was laminated using the same method

as the earlier test piece. A Lycra panel following the pad shape (with 10mm seam allowance around the outside edge) was bonded to the inside surface over each neoprene pad.

Figure 80: Prototyping the hip T-shirt. Left, side panel with left edge seam bonded to front panel. Right, neoprene pad positioned on inside side panel.

Figure 81: Hip T-shirt prototype. Hip pad rising upwards as arm lifts (top); hip pads flipped upwards (bottom left); hip pads tucked into trousers (bottom right).

I was able to wear the prototype garment (see Figure 81) and made these key observations:

- Although the CLO avatar (the model representing the garment wearer) was adjusted to my body measurements, the prototype was too tight fitting around the arms and chest. The tightness was not obvious in the CAD visual, although a 'Fit Map' tool was later used in the software that can illustrate areas of the garment that would be uncomfortable to wear. The tight fit can be easily remedied by adding more fabric across the chest, upper back, and arms.
- The stretch in the Lycra fabric helped to pull the padded sides closer to the hips. This was a distinct advantage compared to the initial hip shirt mock-up. The lower edge around the back of the garment extended further downwards, over the wearer's behind, which also helped to pull both padded sides in closer to the body.

- The semi-rigidity of the padded sides allowed them to be lifted upwards, hinged around the top edge of the laminated neoprene. The elasticity of the Lycra meant that once the pads had been lifted past the horizontal, they snapped upwards towards the sides of the lower torso. They can easily be pushed back down again, into place. This feature seems advantageous in terms of getting the pads out of the way when using the toilet.
- Prototyping the T-shirt revealed a disadvantage that was not spotted in the earlier mock-up. As the panel holding the hip pad is linked directly to the underarm of the garment, when the wearer lifts their arm, there is a tendency for the pad to move upwards too. There was an upward movement of the pad of approximately 80mm between arms down and arms up. This risks the greater trochanter not being covered by the pad during a fall, especially if the wearer lifts their arm up to break their fall. The solution, discussed in the next section, is to use a vest rather than a T-shirt.

5.3.1.3 Refining the hip vest

The hip T-shirt prototype demonstrated that it is possible to integrate hip protection in the lower portion of a garment worn on the upper body. However, the location of the padding is susceptible to upward movement when the wearer lifts their arms. Some initial observations when comparing a vest garment indicated that without the arms, the extent to which the pads would move in the same circumstance is significantly reduced. This principle, however, is explored further later as vest garments are prototyped, and pad stability is investigated (see 5.4.2).

The hip T-shirt concept was quickly translated into a vest design and visualised using CLO software (see Figure 82). Placing women at the centre of the design research, the focus also shifted to visualising a garment with female users in mind. Using anthropometric data for a mature female, the body size of the default CLO avatar was adjusted to a UK size 14 (Aldrich 2011), to more realistically represent the broader population and reflect the medium-large sizing of garments produced by DM Orthotics. The opportunity to develop custom avatars by 3D scanning potential hip protector users is outside the scope of this research project but could be explored in later work. This will be important to respond to the challenges in the variation of body shape among older people. As we age, a decrease in bone and muscle mass, and an increase in fat mass, contribute to changes to the shape, size, posture and movement of our bodies (Bougourd 2015). After the age of 30 we see a gradual decline in bone mass, with a more rapid loss for women following the menopause. The consequences are a loss in height – with the average height of 65–74 year olds being 5 cm less than

the average height of those aged 16–24 (McCann 2012) – increased curvature of the hips and knees, broadening of the feet and flattening of the arches (Bougourd 2015; MedlinePlus 2022). Excessive curvature of the upper portion of the spine (thoracic) will also affect posture and the fit of clothing. "As the spinal column becomes compressed and the back begins to bend over, three things can happen: the shoulders […] can become very rounded, the neck can project forward, and the breadth of 'across back' can increase" (Bougourd 2015: 145). As a result, the hip vest may need a more generous amount of fabric across the back (as suggested by Fanny Karst – see 4.1.3) with shoulder straps that are wider than shown in Figure 82, that are adjustable.

Figure 82: Hip vest render using CLO software.

Muscles decrease in strength, endurance, size and weight as we age, although the rate and extent of change varies between men and women (Bougourd 2015). McCann (2012) notes that, "physical strength is generally related to body size, with women physically weaker than men at all ages, and with weaker muscles and a poorer power-to-weight ratio". This has implications for the strength and

mobility required to put on and take off the hip vest, and the modulus and stretch direction of the garment fabric should be considered to help facilitate this (see 2.3.2).

As muscle mass declines with age, fat mass tends to increase with body weight peaking between the ages of 50-70. However, after 70-75 years a significant decline in weight begins to occur and this older age group have a thinner body frame than younger people. Fat mass in women tends to shift towards the upper body after the menopause where the ratio of waist to hip circumference increases with age for women (Perissinotto et al. 2002). This means a changing female body shape from what is commonly known as a 'pear shape' to a shape more akin a male waist (Bougourd 2015). A knitted fabric with mechanical stretch, and fibres blended with elastane, can be incorporated into the hip vest design to help accommodate a broad range of different body shapes and sizes.

Ultimately, garment sizing and adjustability would have to consider both the users' body shape and size, and the optimum location for hip protector pads. Vertical body length from the hips to the shoulders could be accounted by measuring the user seated, from the seat surface to the bony tip of the shoulder (acromion). In the UK, that measurement is 523mm for 5th %ile females and 622.4mm for 95th %ile, demonstrating a difference of 99.4mm (Department of Trade and Industry 1998). From an off-the-peg sizing perspective, this may mean that small, medium, and large options for body length will be necessary, alongside other sizing factors.

The potential for two-tone colour explored in the hip T-shirt also translated into the vest concept with grey edge binding and shoulder straps. I was interested in how the garment colours could reflect current trends in sportswear designed for women. In February 2021, a review of women's compression, base layers and leggings produced by sportswear manufacturers Nike and Adidas showed a range of colours, including coral pink, olive green, grey and white. The similarity of colours produced by both companies is reflected of the colour forecasting industry and the frequency in which the same colour trends influence brands (Johnston 2015). This small palette provided a starting point for visualising a wider range of coloured hip vests that could be shown to potential users to gain feedback on the concept. Although a range of colours was a desirable feature noted in the online survey and listed in the table of design criteria (see 4.5), colour trends change every season, so it is beyond the scope of this research to identify an 'optimum' colour palette for the hip vest. Johnston also found in her research with mature women that they, "have very strong personal opinions about colour, but very little common choice or agreement about their likes and dislikes" (2015: 40). However, black, white, navy, and cream are considered the 'classic' colours and represent the major financial commitment for most clothing retailers (Johnston 2015). Indeed, white is a practical colour if the garment is worn under other clothing so that it doesn't show through.

Figure 83: Hip vest renders using CLO software (white, grey, coral, and khaki).

To reflect current trends in women's sportswear, I applied a similar colour palette to the hip vest concept and visualised them in CLO software (see Figure 83). The shoulder straps were widened to improve comfort and make the garment easier to prototype (as the straps can be incorporated into the front panel of the garment). Vests with wide, built-up shoulder straps are recommended for women with osteoporosis and a curved spine, as they won't slip down past sloping shoulders (Royal Osteoporosis Society 2022b). The four different coloured versions of the garment were presented to the women who had taken part in earlier focus groups and discussed during a series of telephone interviews.

5.3.2 Hip vest feedback interviews

Four participants took part in the hip vest feedback interviews, all of whom were involved in the initial focus groups with active older people (see 4.2.2) and the Under/Over/Outer focus group (see 5.2.3). Their involvement across these distinct stages of the design research helped to maintain their interest and engagement in the project. They saw how the concepts for new types of hip protection responded to the problems they had discussed early on, becoming an integral part of the Action Research process.

This research tests the design practice against the conceptual framework, especially relating to the meaning-making aspects of the design and the opportunity to develop new products for active living and healthy ageing. In response to the research question, the interviews also explored broader performance requirements and how sociocultural and lifestyle aspirations can be visually reflected through the product.

5.3.2.1 Methodology

The interviews happened whilst social distancing measures were in place, so they were conducted over the telephone. I used the same methods for recording and generating a transcript as the earlier interview conducted this way (see 4.1.3). I adopted a semi-structured approach with a list of questions that invited direct responses about the proposed design concept. I sent the questions to the participants one week in advance along with a PDF image of the design concept (see Figure 84). The image was emailed to three of the participants but printed and posted to the fourth participant who was less confident using email. This allowed participants time to study the design concept and

consider the questions to provide more thoughtful feedback. Responses to these questions are discussed in the next section:

- Initial thoughts and reactions to the product: what three words best describe the garment?
- What might be the advantages and disadvantages of this product compared to underwear hip protectors?
- What type of fabric would you expect it to be made from?
- What are your expectations of the padded area? Hard, soft, rigid, flexible, how thick?
- Where would you expect to buy this product and what brands might you associate with it?

I carefully reviewed the interview recordings, with close attention and comparison of the responses to each specific question (see Appendix O). Themes that occurred during the conversations were noted, helping to validate the design concept but also establish further areas of improvement and other ideas that could be explored.

Figure 84: Hip vest concept presentation for telephone interview participants.

The participants' earlier contributions to the research gave them a good understanding of the issues. Their motivation and engagement with the project meant that their feedback at this stage was meaningful and helpful. The ideas discussed were considered alongside data from the online survey, where feedback relating to context of use, style, and the prioritisation of design features for new types of hip protection, was carefully examined to ratify design decisions moving forward.

5.3.2.2 Hip vest interview discussion

All four participants responded positively when seeing the design proposal for the first time. This was reflected in the words they chose that best described the garment:

- Practical
- Wearable
- Suitable (for men and women)
- Smooth
- Comforting
- Smart
- Modern
- Attractive
- Simple

Not all the participants were able to come up with three words but 'practical' was mentioned on two occasions. 'Practical', 'wearable', 'modern', and 'attractive' are all frequent terms that appear in the word cloud analysis of the online survey for respondents who liked the look of the padded belt hip protector (see 4.3.3.1). 'Simple' is also the most preferred style choice for hip protectors reported in the online survey (56%, n=91) (see 4.3.5.2). These visceral responses to the design are encouraging and demonstrate that the meanings expressed through the garment are interpreted in a positive way. The comments also indicated how the design challenges the meanings associated with current types of hip protectors the participants had already been introduced to. One of the women particularly liked the vest top as she was used to wearing a camisole, so the familiarity of the visual language appealed to her. Similarly, another participant stated, "it looks normal. I'd be happy to be seen in something like that". The shift from a medical product to a consumer product was also reflected with another woman noting, "I wouldn't complain about wearing anything like that because it doesn't look like a surgical garment".

Having discussed underwear hip protectors during earlier focus groups, the participants were able to consider how the hip vest concept may have advantages or disadvantages compared to their traditional counterpart. The themes discussed are summarised in Table 21.

Table 21: Summary of reported advantages and disadvantages of hip vest compared to underwear hip protectors.

Advantages	Disadvantages
Looks wearable	Difficult to get on and off
Looks feminine	Fit for different body sizes
Not 'surgical' looking	Too warm in hot weather
Colour options	Laundering could be difficult
Like a sports top	Pads rubbing against skin
Easy to get on and off	Could impede movement, sitting and standing
	Could ride up

There was little consensus on the advantages and disadvantages with only the colour options and ease or difficulty to get on or off, mentioned by more than one participant. For the latter, one woman with experience of tight-fitting hernia support vests felt it could be difficult, but another noted, "it would be easier for me to put over my head like a jumper". An option for a front opening garment, e.g., with a zip, could be considered for people who would struggle to step into the vest, or pull it over their head.

The reported advantages echoed some of the earlier points made, such as looking wearable and not looking like a medical garment. One woman commented on how it looked like a sports top, adding, "I was pleasantly surprised with it. Although I'm elderly […] I like anything that is – how can I put it – not 'old-peopley'". She went on to note that, "it will well serve the purpose, but it also looks feminine". A sporty aesthetic and feminine appearance are two design criteria determined earlier (see 4.5).

Three of the participants mentioned the colours and were supportive of having a choice of colour. One woman commented how the colours, "make it more appealing", but noted more generic colours of black, grey, navy and cream, would have wider appeal, as described by Johnston (2015).

In terms of disadvantages, one participant pointed out that, "everybody's got different body lengths". The fit of the garment will be contingent on the length of the torso and not just the hip and waist measurements. This adds another parameter for sizing which will also be affected by a changing body shape with age, especially more rounded shoulders or back. Most of DM Orthotics' garments are made to order based on an individual's requirements, so a good fit can be certain in that situation. However, as described earlier, an off-the-peg garment may require more size options than an equivalent sports vest, to guarantee the correct positioning of the hip protector pad.

The potential seasonality of the garment was noted: “I don’t know whether in summertime [that] people would want to wear that extra layer”. This is a disadvantage but perhaps less so in climates like the UK. As a base layer, it would certainly provide more thermal insulation, but the vest top could also be worn on its own for exercising or during warm weather.

One participant was concerned about laundering the garment, comparing the fabric and padding to padded bras. She noted, “no matter how careful you were […] washing them, they sometimes changed. Either the texture changed or the colour”. Testing on the colour fastness and washing durability of specified fabrics would need to be conducted but is outside the scope of this investigation. The protective padding on the hip vest concept is laminated into the side panels of the garment. If laundering were to diminish the impact absorbing properties of the pad, then it would be better for them to be removeable. Another woman considered that water might be absorbed by the pads when washing which would take a long time to dry. These are two good reasons to design the padding so that it can be separated from the vest.

Other reported disadvantages, such as pads rubbing against the skin and impeding movement, are areas that are investigated through further prototyping and physical testing (see 5.4.2). Critical to both issues are the size, thickness, and flexibility of the protective pads, issues that are explored later though the development of 3D printed lattice solutions (see 5.3.3) that are removable from the garment. One participant concerned that the garment might “curl up”, suggested adding a leotard type fastening to the crotch. This would more securely locate the lower part of the garment but could impact on the ease of use, especially using the toilet. This is another area explored in the product user evaluation (see 5.4.2).

There was much more consensus when their expectations around the fabric and padding materials were discussed. All the participants agreed the fabric should be stretchy, and a cotton and Lycra blend was suggested by two of the women, where cotton was noted for its coolness against the body. Further consideration into the technical specification of appropriate fabrics would be needed reflecting the examples discussed in the contextual review (see 2.3.2). The expectations relating to the hip padding echoed earlier feedback through focus groups and the online survey. Comments included how the pad needed to be soft and flexible enough for comfort, but resistant and firm enough for protection. The thickness of the material was mentioned, but not a specific measurement for acceptable thickness. For example, one participant noted that, “you wouldn't want it too thick, and not too heavy”.

Regarding where they would expect to buy the product, one of the participants envisaged a bespoke fitted garment that could be collected from a pharmacist. The medical connotation is perhaps a

reflection of her experience of using orthotic garments. However, three of the women suggested the retailer, Marks & Spencer (M&S). For one participant, her explanation was simply, “because that’s where I buy all my underwear, always have done”. One in three British women buy their bras at M&S (Sutherland 2020) and the retailer sells more than 70 million pairs of knickers every year (Marks & Spencer 2024). The view of the hip vest concept as an M&S product demonstrates the perception of it as a type of underwear, but also aligns it with the socio-cultural and lifestyle aspirations of the participants. This is an important point, responding directly to the research question and challenging the cultural negotiation of the meanings communicated through current forms of hip protectors.

In discussing where the garment might be bought, the subject of cost was also raised. The participants expected to pay between £20 to £35 for the hip vest product. This is comparable to equivalent sportswear tops, such as the Nike Dri-FIT One, women’s tank top that retails at £27.95 (Nike 2023b). However, this is a lower cost compared to current underwear hip protector products where, for example, hip protectors manufactured by Bort, LYDS and WonderHips, retail between £50 and £70 per product (Andrews 2019). The discrepancy is likely due to lower production volumes, the cost of impact absorbing materials, and amortising R&D costs. Although the commercialisation of design outcomes is beyond the scope of this investigation, it is useful to understand consumer expectations of the market for future work.

The responses towards the hip vest concept were positive overall, providing some encouraging evidence for the validity of the idea. Alongside the earlier research, and design criteria established in section 4.5, the findings provide a solid rationale for developing the vest concept further. Some key areas of discussion prompted further investigation, especially relating to freedom of movement when wearing the garment, ease of getting the vest on or off, and designs for removable protector pads (with reference to laundering). These areas are explored further, starting with an exploration into hip pad design using flexible 3D printed lattices.

5.3.3 3D printed lattice hip pad

The earlier investigation into flexible 3D printed lattices (see 5.2.1.3) provided an initial understanding of:

- How to create lattice geometry using Autodesk Netfabb software;
- Selective Laser Sintering (SLS), Multi Jet Fusion (MJF), and Stereolithography (SLA): 3D printing processes appropriate for producing fine detailed parts such as lattices;

- The visual and tactile qualities of four samples produced using these processes in a range of flexible materials.

In this section, I have translated the learning from these early experiments into design concepts for protective hip protector pads. In particular, the development of a pad design with an integral lattice structure that will provide enough coverage to protect the hip area (responding to Minns et al. (2007) specification for pad design – see 5.2.1.1). Continuing with the development of the hip vest concept, the relationship between the protective pads and the garment is also investigated.

5.3.3.1 Hip pad from body scan

I have included an investigation into 3D scanning and a workflow to translate the scans of a user's waist and hips into the shape of a hip protector pad, in Appendix L. The scanned surface of the mannequin hip was used to directly control the shape of a pad developed in Autodesk Inventor software. As discussed in section 5.1.3, this method was later disregarded as the protective pad would need a flexible form to accommodate the user sitting, standing, walking, etc. However, the processes discussed below provided the starting point for the investigation of 3D printed lattices integrated into a hip protector pad that could be employed with the hip vest concept.

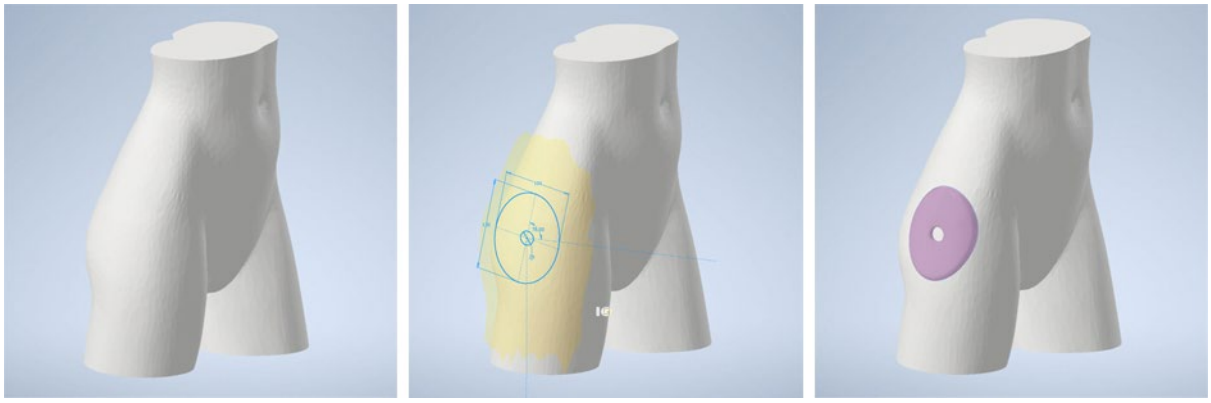


Figure 85: Developing a hip pad from 3D scan data. Left, 3D scan of mannequin; Centre, 20mm offset region of hip surface (yellow area) and sketch to define pad shape; Right, oval pad (coloured pink) created between the offset surface and hip surface.

An area of the hip surface over the greater trochanter was offset to coincide with where the outer surface of the hip pad would be (shown in centre image on Figure 85). The offset distance from the surface of the mannequin hip model was 20mm to represent a pad thickness generalisable across

existing hip protector garments (Laing et al. 2011). The offset surface (which has a thickness of zero) was then 'thickened' by 20mm to bring the inside face back to the surface of the hip CAD model. Finally, this new 'body' was trimmed to create an oval shaped object with fillets added to round off sharp edges. In this first instance, a pad shape was created to cover the greater trochanter, but could be made larger to accommodate the region extents recommended by Minns et al. (2007). The hole in the centre of the pad was proposed in response to novel hip protector pads, such as SafeHip's Horseshoe design that both absorbs and disperses impact energy away from the critical area (Tytex 2024). The wearer would be able to feel through the hole to ensure the pad was positioned directly over the greater trochanter. This concept was later abandoned, as the pad design became thinner, to offer as much protection over the area as possible.

When a lattice structure is fitted to a shape, it is known as a conformal lattice (Brennan-Craddock et al. 2012). In this first attempt of a hip pad with a conformal lattice, I explored the capability of Autodesk Netfabb software to deal with more complex forms, as opposed to the square samples developed earlier (see 5.2.1.3). The hip protector pad created from the 3D scanned hip surface (shown in the right-hand image in Figure 85), was a solid CAD model. This part was imported into Autodesk Netfabb where it was converted into a 10x10x10mm cell sized 'Star' lattice. I chose this lattice style because it shared similar visual characteristics to the lattice used to create the midsole of the Futurecraft 4D running shoe discussed in the contextual review (see 2.3.4). The exposed structure communicates the high-tech and sophisticated aesthetic of a performance sportswear garment.

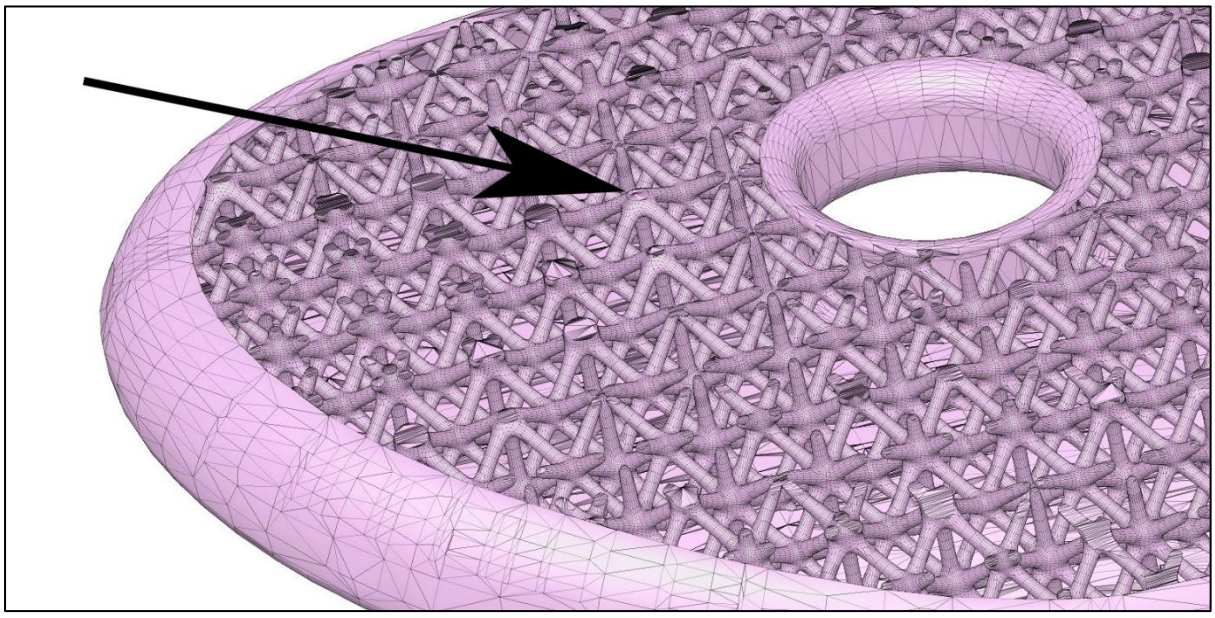


Figure 86: Detail of hip pad (LHP001) CAD model showing exposed internal lattice structure.

A duplication of the same original part was imported into Netfabb, but this version was shelled, with material removed from its interior leaving a hollow cavity with a 1mm wall thickness. Both the latticed part and the shelled version were brought together to create a single pad design, from here on described as LHP001 (see Figure 86). The upper surface of the part was deleted from the CAD model so excess powder or resin could be easily removed if it was 3D printed. The resulting visibility of the lattice also echoes the visual language used in the sports footwear. The arrow in Figure 86 indicates where the beams at one section of the lattice terminate neatly to a single point. However, where the lattice was trimmed to exactly fit the envelope of the shelled hip pad part, it left many open beams and incomplete cells. The same principle is demonstrated in Figure 87 where the cells in lattice A are a consistent shape and size internally but are trimmed to the outside edges of the conformal shape. This could affect the energy absorbing capability of the part, but also look unresolved and unsightly.

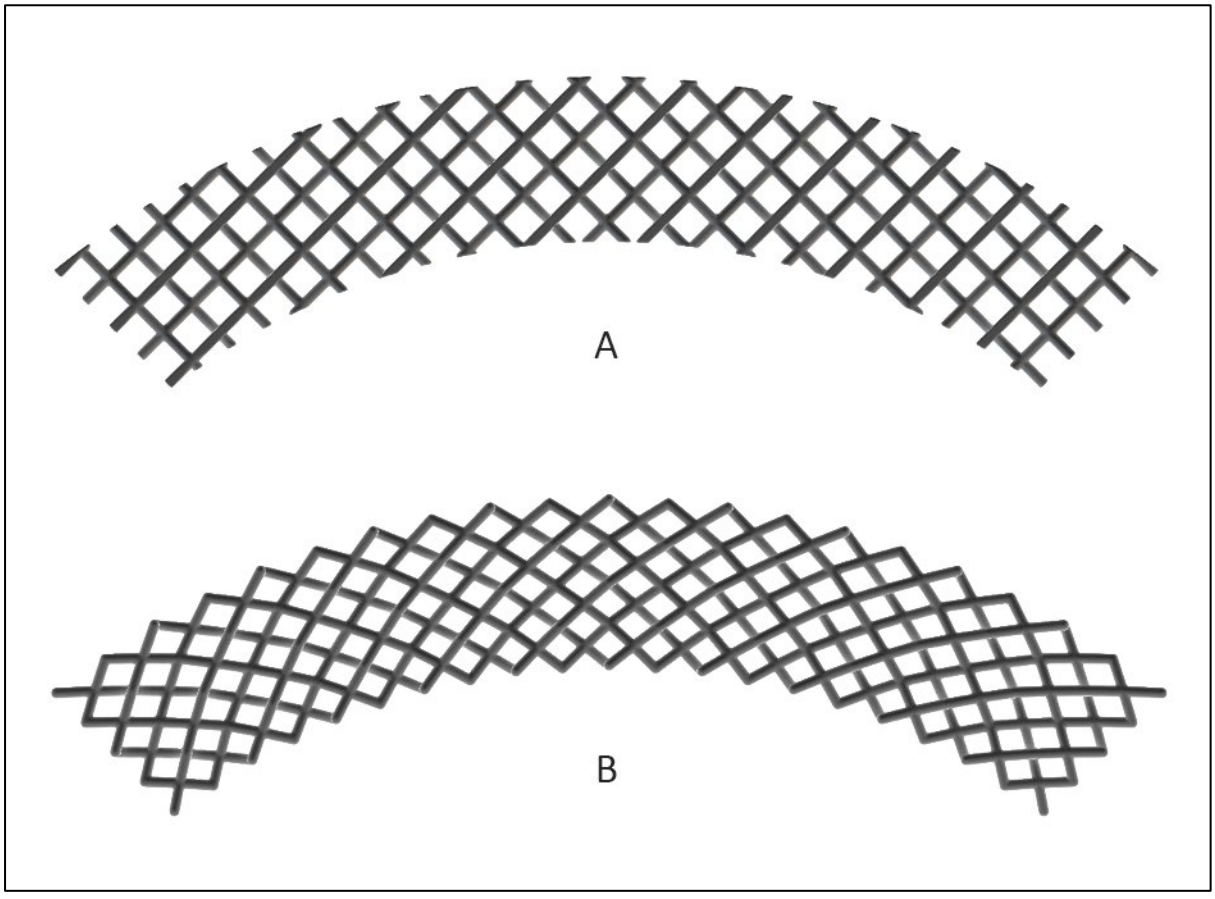


Figure 87: Conformal lattice methods: (A) trimmed lattice; (B) swept lattice.

Using a swept conformal lattice method (see Figure 87, B) the overall physical integrity of the cells could be maintained whilst presenting a more visually refined appearance to the 3D printed part. However, it was not possible to produce swept conformal lattices using Autodesk Netfabb software.

The process presented here fostered a technical understanding of digital design outputs, but also began a critical exploration of the aesthetics of a 3D printed hip pad with a lattice structure. The precedent of this technology being used in a running shoe midsole resonated with the ambition to develop a hip protector garment expressing a sporty visual language. It was clear, however, that a swept conformal lattice method needed to be investigated. I began working with, nTop (formerly nTopology), a software used to create complex geometries, to develop 3D-printed parts (nTop 2024). This allowed more creative control of the conformal lattice design, resulting in the investigation discussed below.

5.3.3.2 Prototyping a 3D printed hip pad

The second iteration of a hip pad with a conformal lattice structure was developed into a 3D printed prototype. Unlike LHP001, this design emerged in direct response to the hip vest concept. Where the laminated foam padding appeared as an embossed feature over the hip, the intention was instead to reveal the visually intriguing lattice structure. This was conceived by means of an internal pocket the pad could fit into, with an elasticated cut out window through which the outer surface of the pad would be exposed. The concept follows the earlier ideas explored in the digital montage inspired by protective clothing at the ISPO 2019 trade fair (see Figure 77 in section 5.3.1.1).

Through discussion and drawings provided to DM Orthotics, they produced a prototype vest with the pocket detail to accommodate the 3D printed pad (see Figure 88). This was the first of a series of vests to be prototyped, the development of which will be discussed in more detail later (see 5.4.3.2). The pad (LHP002) was 3D printed on a Formlabs Form2 SLA printer using the 'Flexible Resin' material described in section 5.2.1.3. The silhouette profile of the pad evolved from the central element of the laminated padding concept with sides that taper to align with the shape of the garment side panel. The outer edge of the pad is stepped providing a recessed surface for the elasticate window on the garment to grip over. This detail was more effective on the lower portion of the pad where the elastic had a larger radius to follow. Using nTop software, a Kelvin cell lattice was applied using the swept conformal lattice method. This produced a consistent lattice structure visible through the upper and lower surfaces with no incomplete cells, like example 'B' in Figure 87.

Figure 88: 3D printed lattice hip pad prototype (LHP002). Left, pad fitted into prototype vest manufactured by DM Orthotics. Right, hip pad outer surface detail.

The pad length is 170mm and width is 140mm; a similar size to the Fall Safe hip protector pad (180 x 140mm) and within the dimensions recommended by Minns et al. (2007). Including support material, this allowed it to fit within the build envelope of the Formlabs Form2 SLA 3D printer of 145x145x175mm. At this stage, the process was simply to understand the methods to produce the part in CAD software and 3D print it in a flexible material. The pad thickness of 12mm was therefore not derived from an understanding of its energy absorbing potential (although this is explored later in section 5.4.1) but the median between the 6mm thickness of the Poron XRD material (used in the Protex HiP padded belt) and the 18mm thickness of the polyurethane PBDMS composite material of the Fall Safe pad. This reflects an attempt to reduce the bulkiness of the pad (a well reported barrier from the earlier research – see 4.5) whilst being able to accommodate two rows of lattice cells at a printable scale. The overall shape of LHP002 was produced in Autodesk Inventor software before being imported into nTop to create the conformal lattice. The steps to produce the hip pad CAD model are illustrated in Figure 89 and described below.

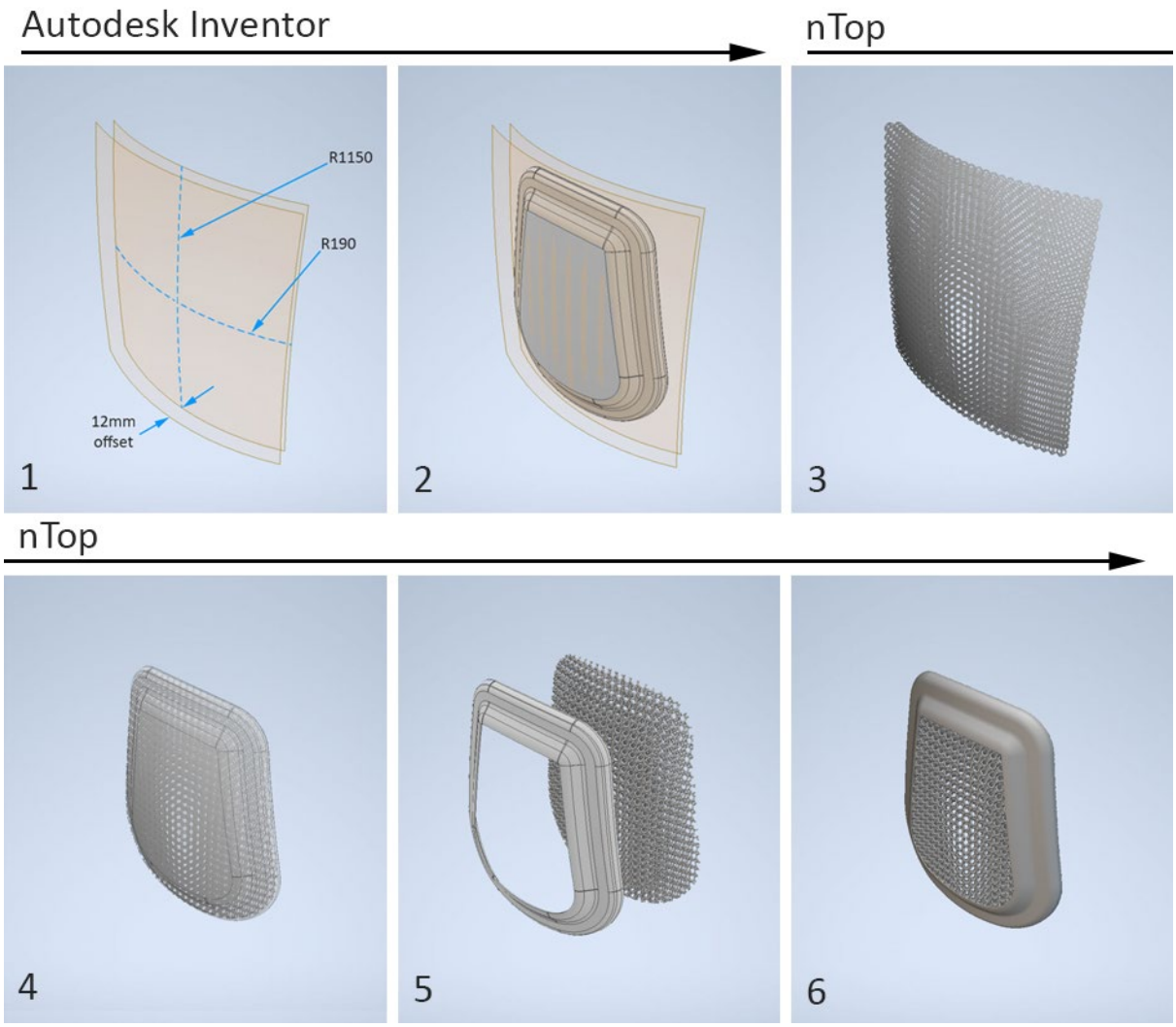


Figure 89: Sequence of steps illustrating how the hip pad (LHP002) CAD model was developed using Autodesk Inventor and nTop software.

1. The inside surface of the pad (the surface that sits directly over the hip) was modelled with a duplicated surface offset by 12mm to accommodate the pad thickness. The surface is a compound curve approximating the shape of the hip derived from the mannequin scan. It comprises of a 190mm radius through the XZ plane and a 1150mm radius through the XY plane. Although these dimensions could be adjusted for different body sizes, the flexibility of the 3D printed part allows it to be pressed flat or curved to much tighter radii in both directions, offering a considerably forgiving fit.
2. The overall pad shape was developed by building the solid part between the inner and outer surfaces described above.
3. The pad part and two surfaces were imported as a native file into the nTop software. The inner and outer surfaces were used to form the swept conformal lattice. The pad part is hidden in this view.

4. The pad part was used as a trimming tool to trim the lattice along the cells that contact the inside surface of the part. The parts of the lattice not within the boundary of the pad part were deleted.
5. A shelled version of the pad with 1mm wall thickness and an open top surface was generated from the original file in Autodesk Inventor and imported into the nTop file. This was joined to the remaining lattice structure which was given a 1mm beam thickness.
6. Finally, the completed part was exported as an STL file, a universally recognised format for 3D printing (Adobe 2024b).

The sequence described above is a simplified account to communicate the key development steps. The actual process took much experimentation to get right whilst learning how to use the nTop software. I adopted the same methodology for further iterations of the 3D printed hip protector pad which are discussed later in the thesis.

The final hip pad CAD model (STL file) was imported into PreForm, software used for 3D printing set up, management, and monitoring using Formlabs machines (Formlabs 2024b). Software diagnostics were used to troubleshoot potential build errors, and support material was added to fix the part to a stable base during the build process. The part took 10.25 hours to build and afterwards was cleaned in a propriety washing unit with isopropyl alcohol (IPA) for 10 minutes to remove the excess resin. Finally, the part was cured for a further 10 minutes in a UV cure tank. The washing and curing times are recommended by Formlabs for the Flexible Resin material. The build time and post-build processing requirements make this a prototyping method only. This provides a means of evaluating the viability of a 3D printed lattice hip pad whilst manufacturers such as Carbon use automated processes to offer production of 3D printed functional parts at scale (Carbon 2024b).

Figure 90 shows the part standing upright before I removed the support material with wire cutters. A small circular mark remained at every point where the support material contacted the part surface. These ‘witness marks’ are visible on the lower portion of the part shown in Figure 88 in addition to a small slit where the print failed. The failed print is indicative of the part requiring more support material around that area. As such, later iterations of a 3D printed hip pad sought ways to remove or disguise marks on the surface caused by support material, especially if more would be needed to avoid a failed print.

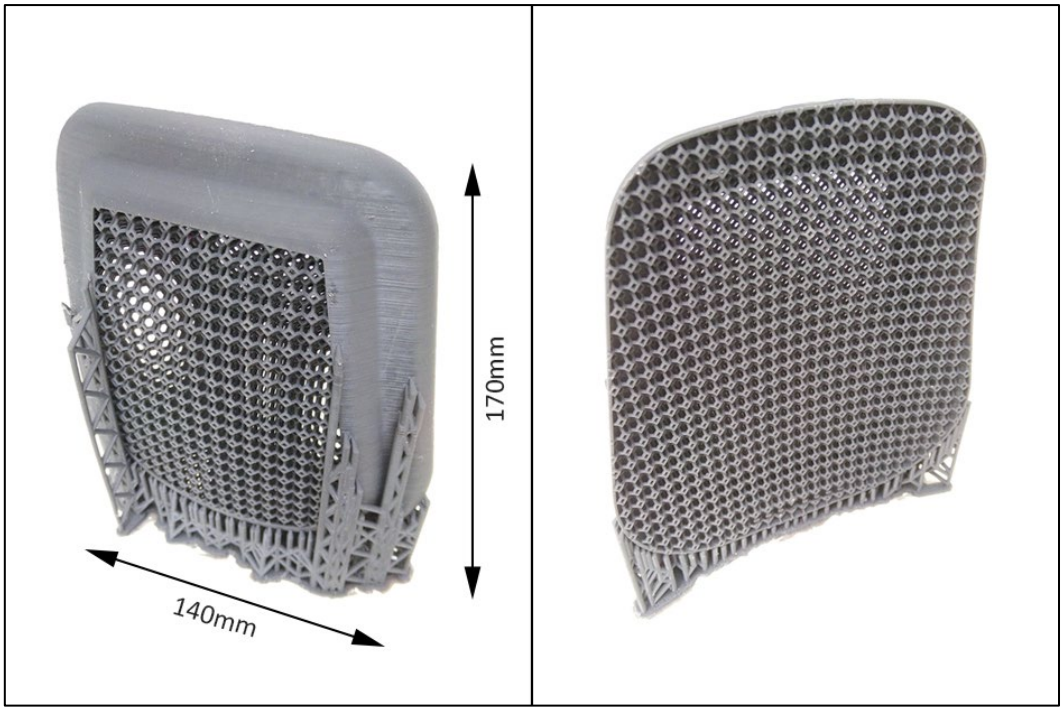


Figure 90: Front and rear of the 3D printed lattice hip pad (LHP002) with build support material still attached.

A method of producing a flexible 3D printed hip pad with a swept conformal lattice has now been demonstrated. Overcoming the effects of the support material to the surface quality, and avoiding build failures, is a concern explored next. This is investigated in relation to the prototype hip vest garment, and later exploration of the force attenuation properties of flexible 3D printed lattice structures.

5.3.3.3 Refining the 3D printed hip pad

The design investigation continued exploring how the hip pad could be further refined. Through the Action Research cycle, evaluation of the first flexible 3D printed hip pad (LHP002) prompted ideas for improvement that could be tested with further prototypes. The next iteration (LPH003) comprised of a smaller test piece (see Figure 91) to investigate how the design could be improved.

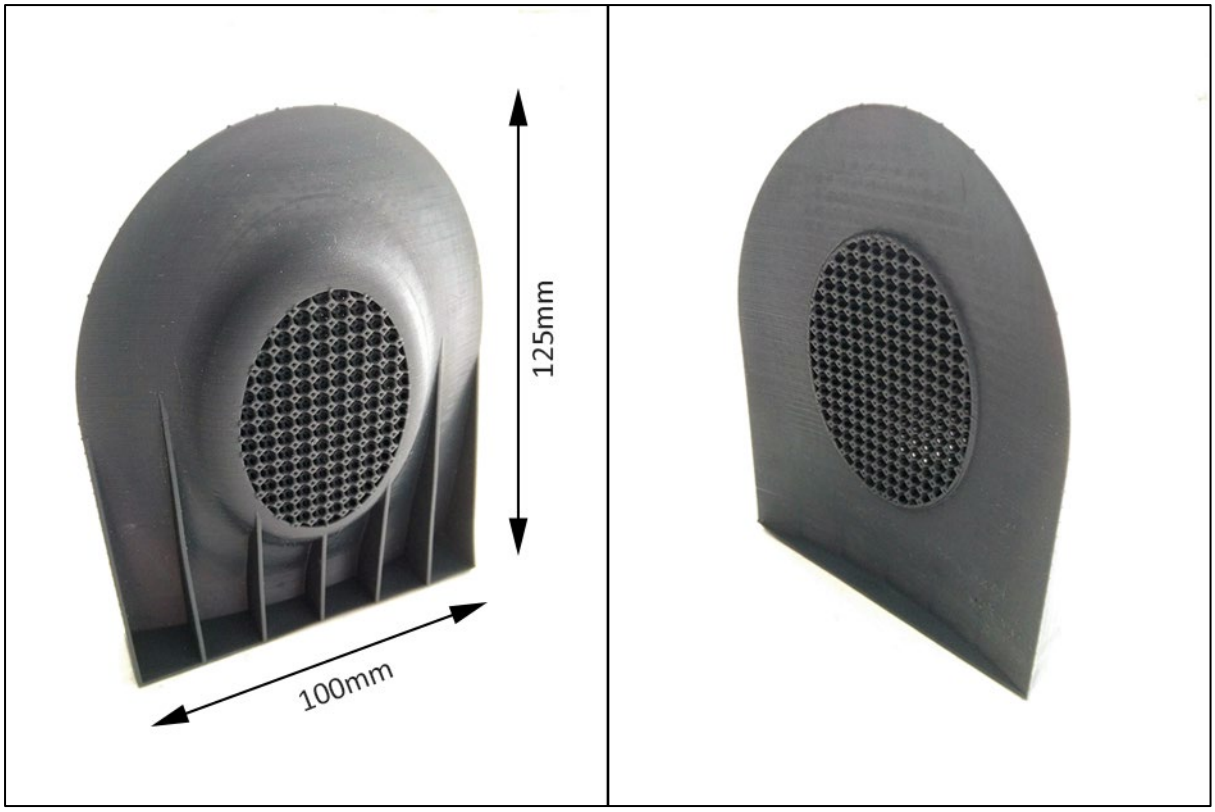


Figure 91: Front and rear of 3D lattice hip pad test piece (LHP003).

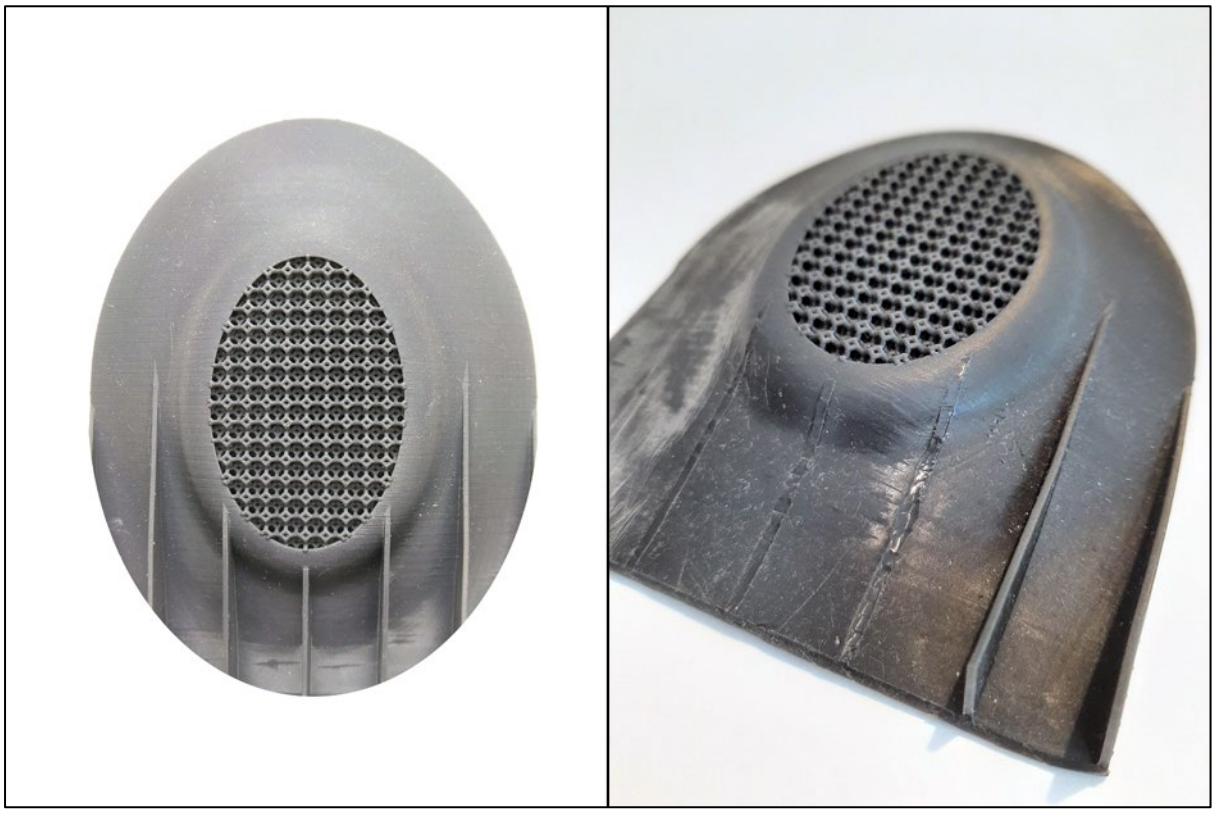


Figure 92: Trimming the hip pad test piece (LHP003). Left, representation of pad trimmed to oval shape. Right, pad detail after actual attempt to trim the base and ribs.

I explored how the surface quality after removing support material could be improved, but also the comfort, discreetness, and impact absorbing capability of the hip pad. On LHP002, unsightly marks were left on the surface where the support material had been removed. In this next iteration, the test piece was designed with a rectangular base and seven integrated support ribs, all 1mm thick. Notionally, these could be trimmed away to leave an oval shaped pad and five vertical lines where the ribs lay. The consistency of the vertical lines could be integrated into the overall visual appearance of the pads as opposed to the pockmarked surface seen on the earlier iteration. In practice, it proved difficult to maintain a consistent finish when trimming the ribs to the surface (see Figure 92). However, the design meant that the part could be 3D printed without the need for build support material to be applied. Figure 93 shows the test piece suspended from the build plate of the Formlabs Form 3 machine before it was removed for washing and curing.

Figure 93: Hip pad test piece (LHP003) suspended on the Formlabs Form 3 build plate after printing.

LHP003 is 12mm thick across the central area of the lattice but tapers down to a thickness of 1mm around the outside edge. This is in response to feedback through the online survey (see 4.3.3) for pads to be shaped to the form of the body to make them less obvious. Tapering the sides would help to blend the edge into the garment to hide the outer profile of the pad seen through clothing. The tapered profile could also help avoid the sensation of the pad edges digging into the body, an issue with hard-shell hip protectors (Doherty et al. 2004). The method for creating the tapered edge combined with the lattice was proven using Autodesk Inventor and nTop software. The viability of the tapering to a 1mm edge thickness was demonstrated through the successful 3D printed part using Formlabs Flexible Resin material. This principle would be applied to later iterations of the hip pad.

The original flexible 3D printed lattice parts (see 5.2.1.3) had a cell size of 10x10x10mm. LHP002 had a cell size of 6x6x6mm, accommodating two rows of cells within the 12mm part thickness. Both parts had a lattice beam thickness of 1mm. Comparing the parts printed in the Formlabs Flexible Resin, the reduced cell sized made the lattice feel firmer when compressed. Intuitively, a smaller, tighter lattice, reflective of the cellular structure of foam that the Kelvin cell imitates, will compress less easily than a larger lattice structure where the cells collapse very easily. This has implications for the energy absorbing properties of the lattice that requires further exploration. LHP003 was produced with a smaller cell size of 4x4x4mm and a beam thickness of 0.8mm. Unlike the earlier iteration, three rows of cells made up the 12mm part thickness. Primarily, this was to see how successfully the part would print, which it did without any issues. As I found comparing the earlier two samples, LHP003 feels firmer to the touch when compressed than LHP002. This observation precedes the investigation into the energy absorbing properties of 3D printed lattices explored later (see 5.4.1).

Following LHP003, another hip pad prototype (LHP004) was developed that could be integrated into the vest produced by DM Orthotics (see Figure 94). I produced the CAD model using the same method as LHP002, although with this new part the LHP003 kelvin cell geometry was applied. This meant that the pad accommodated three rows of the lattice structure with a cell size of 4x4x4mm, although the overall pad thickness was 12.8mm after allowing for the lattice beam thickness.

Figure 94: 3D printed lattice hip pad prototype (LHP004). Left, pad fitted into prototype vest manufactured by DM Orthotics. Right, hip pad outer surface detail.

The stepped profile from LHP002 was removed in favour of a simpler chamfered shape where the outer edge of the exposed lattice broadly follows the shape of the elasticated cut-out window in the vest. This afforded a slightly more generous width of 151mm compared to LHP002 (140mm width) and allowed for a snugger fit in the vest pocket. The height of 170mm remined the same, constrained by the maximum build height of the Formlabs Form 3 printer. By this stage, Formlabs had discontinued sale of the Flexible Resin and replaced it with a clear 'Flexible 80A' resin. The new resin (discussed in 5.2.1.3) is an improvement both from a visual and tactile perspective. Its translucency allows the lattice structure detail to be seen through the surface, and the material has a softer, more 'rubber-like' feel to it.

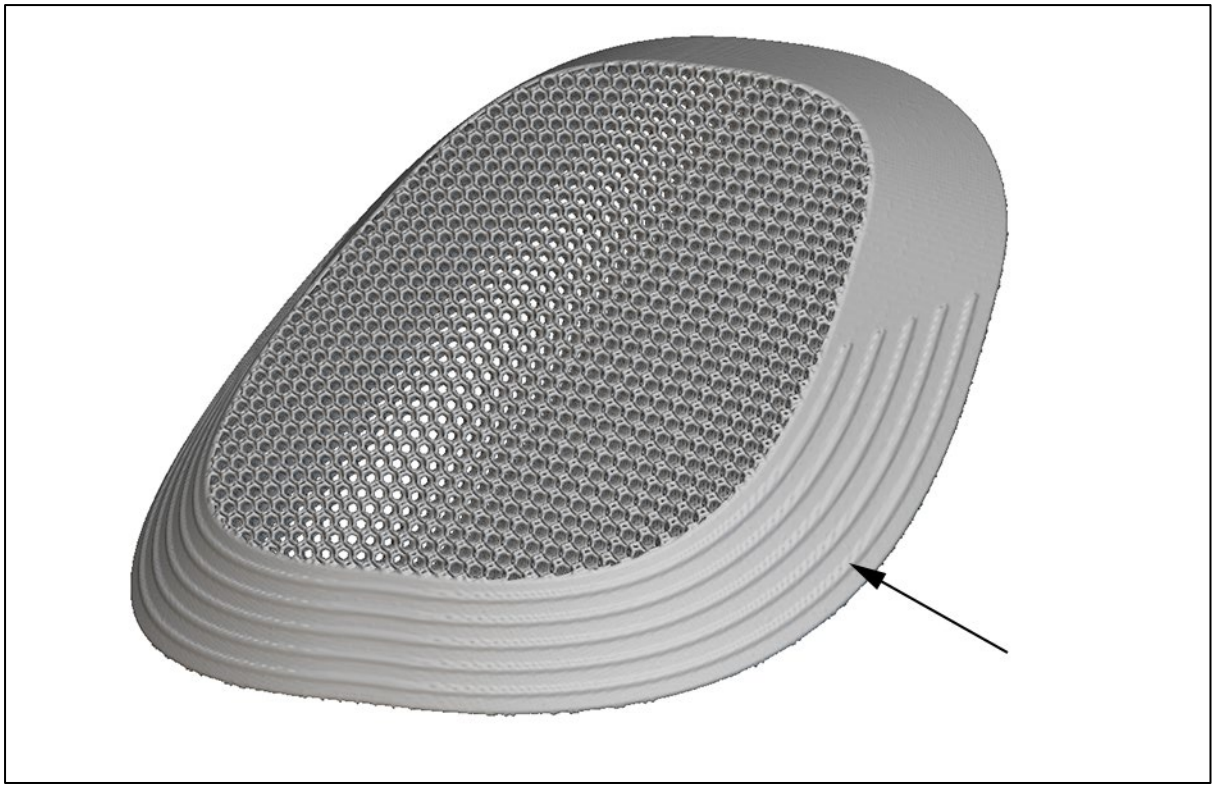


Figure 95: 3D printed lattice hip pad (LHP004) CAD model with arrow indicating outermost embossed rib.

The translucent surface is also more forgiving at hiding the witness marks left after the build support material has been removed. However, for LHP004 a series of five narrow embossed ribs (2mm wide and 0.3mm high) were positioned around the lower portion of the part to provide a location point to attach support material to the model (see Figure 95). The raised profile of each rib provides a uniform surface to trim back the support material with a sharp blade, helping to disguise the witness marks. The ribs allow the even distribution of the support material location points but also create a subtle pattern on the pad surface in keeping with the overall pad design.

Figure 96 shows the CAD model with build support material in the PreForm software used to prepare the 3D print. The image shows the orientation of the part diagonally across the build plate and demonstrates how the size is close to the maximum capacity of the Form 3 machine. This part took longer to build (15 hrs 30 mins) compared to LHP002 due to the increase in support material and denser lattice structure. However, this part had no build failures across the lower face.

Figure 97 shows the build support material being removed from the lower region of the LHP004 prototype. Some of the material would simply detach from the part when pulled, but I used a scalpel to remove any of the remaining support structure. The scalpel was passed over the surface of the embossed ribs to remove any other remnants of the support material.

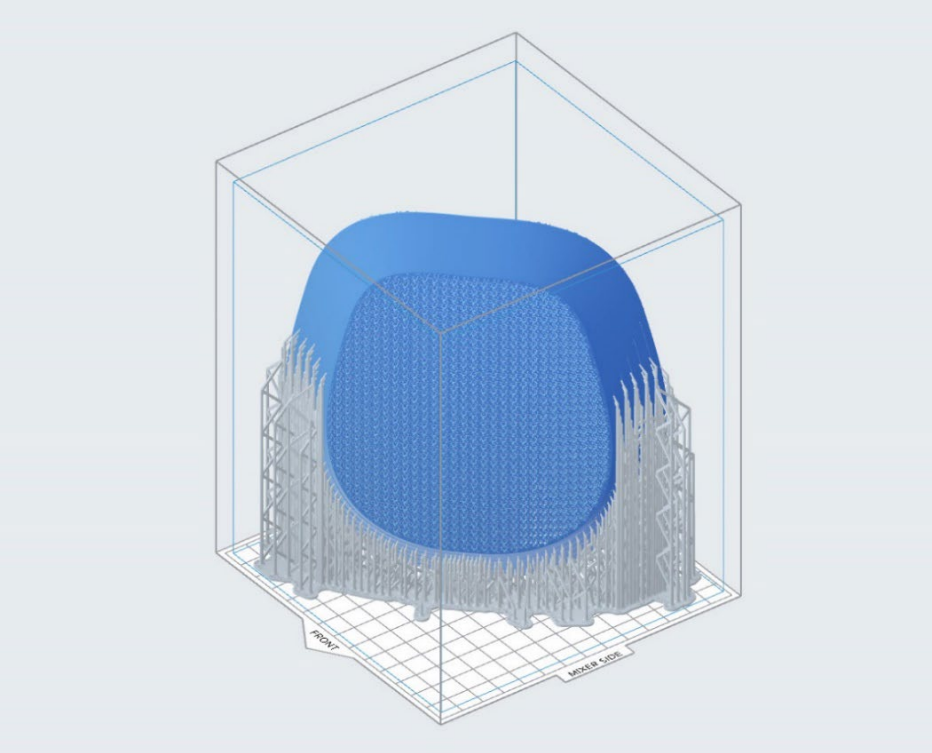


Figure 96: 3D printed lattice hip pad (LHP004) CAD model in PreForm software showing build support material.

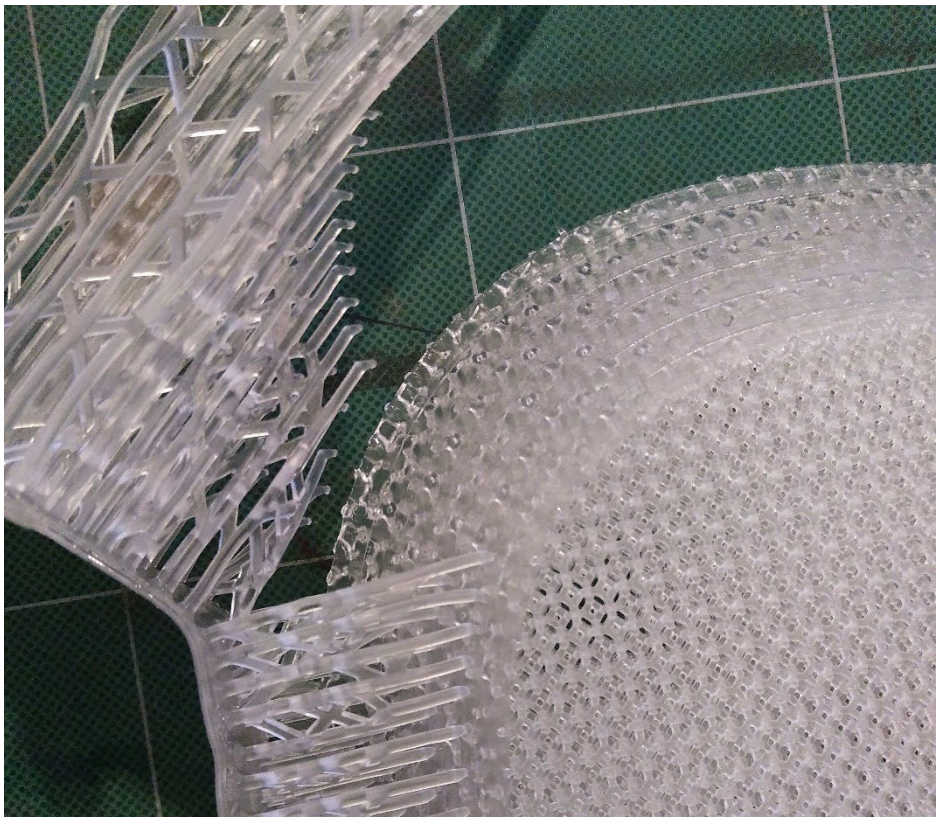


Figure 97: Detail of lower left section of LHP004 during the removal of the build support material.

The visual appearance of LHP004, resolution of the 3D print, and overall feel of the flexible lattice were very positive indicators of the viability of this concept. The processes presented here demonstrate how an understanding of the design and manufacture of a 3D printed lattice hip pad has emerged through the iterative development embodied in Action Research. The flexible lattice structure, and Kelvin cell in particular, was used for its reported impact energy absorbing properties. However, a closer investigation into the force attenuation of 3D printed prototypes is explored later.

5.3.4 Reflection

In this section, I have reported on research *through* design of the hip vest concept, including establishing a method for producing flexible 3D printed lattice hip pads. Earlier exploration into protective tiled surfaces considered how the protection itself could embrace a visually pleasing aesthetic, particularly for hip protectors worn over clothing. However, this investigation was superseded by the hip vest development where the ubiquity of the garment reflects the demand for hip protection that expresses social-cultural norms. There is potential for the protective tiled surface concept to be explored as part of the vest, but for now the investigation into flexible 3D printed lattice hip pads has yielded a potential design solution that could be easily separated from the garment. This is an important requirement for ease of laundering, a point echoed in the hip vest feedback interviews (see 5.3.2.2).

The rationale for the hip vest concept, as opposed to a T-shirt, has been determined through prototyping, noting the comparatively stable positioning of the hip pad on a garment without sleeves. Other advantages of the vest compared to underwear hip protectors include not needing to remove the garment when using the toilet, and some versatility on how to put it on, i.e., step through and pull up, or pull down over your head, and conversely to take off. Unlike belt style hip protectors, a vest will be less prone to twisting with the risk of hip pads moving out of position.

The hip vest feedback interviews provided some positive responses to the proposal embracing a sporty aesthetic. Further investigation is needed relating to garment sizing, freedom of movement when wearing the hip vest, and ease of getting the vest on or off. Later exploration of the 3D printed lattice hip pad also sought to reflect the visual language of performance sportswear as seen in running shoes manufactured by Adidas. Both the vest garment and the 3D printed lattice hip pad concepts demonstrate good potential to fulfil the design criteria presented in section 4.5. Some initial work has been done to explore the relationship between these two components, but further

development is needed to investigate both the aesthetic and functional requirements of the pads and vest combination.

At this stage, it is helpful to re-visit the discussion at the end of section 4.5 and reflect on the conceptual framework as a lens through which the design practice is evaluated. Firstly, to consider hip protector design informed by both medical and social models of development, reflecting physical and psychological needs of users:

Innovation through a 3D printed lattice hip pad responds to both the physical and psychological needs of users. The known force attenuation properties of the Kelvin cell lattice has the potential to reduce the impact force caused by a fall at the femoral neck (Habib 2020). The flexibility, lightness, and tactile softness of the Formlabs Flexible 80A material is also encouraging from a comfort perspective. The bulkiness of current hip protector pads is a well reported barrier to their use, impacting on the psychological needs of users, particularly relating to their self-image. The ongoing investigation into 3D printed lattice hip pads will explore how the technology will allow for thinner energy absorbing surfaces that can be shaped more sensitively to the form of the body. In response to related design requirements discussed in section 4.5, the hip vest concept has less bulky and more discreet padding, embraces different colour options, and has a sporty and feminine style designed for women.

Secondly, to consider hip protector design that explores the cultural negotiation of their meanings, recognising they are neither fixed nor absolute and are context dependent:

The hip vest concept challenges the meanings associated with current underwear hip protectors located in terms such as ‘medical’, ‘clinical’, ‘elderly’, and ‘old person’. The vest design removes the association between hip protection and specialist underwear, and the contexts of vulnerability and self-consciousness related to incontinence products. The hip vest concept was described by interviewees as ‘simple’ and ‘feminine’, embracing key aspects of the visual language preferred by the online survey respondents. The sporty aesthetic, discussed in section 4.5 as an important attribute to inspire confidence for activity and movement, was also noted in the hip vest feedback interviews. However, the design of vest garments more broadly relates to a variety of user and scenario contexts. For example, it is a style of garment worn by women and men, and could include an underwear base layer, a summer top, or exercise wear. The shoulder straps could be wide or narrow, adjustable (especially for women), and have a variety of colours or prints. The versatility of the garment could therefore offer hip protection responding to differing user needs across a wide range of contexts. When reflected through the personas (see 4.4), the style conscious, Wendy, who enjoys the outdoors might be happy to wear a sporty vest, visible to others, whilst exercising.

However, Greta, who is less active and prioritises discreet and comfortable hip protection, may prefer a more feminine and understated vest design specifically as underwear. A closer look at how the personas could respond to design concepts is reported in section 5.4.2.3.

Finally, to consider hip protector design as critical gerontology, challenging ageist attitudes and developing new products that empower healthy ageing:

The ubiquity of the vest design responds well to the critical gerontological perspective of shifting the emphasis away from 'age' as a determinant for wearing hip protectors, and placing the focus on 'fall risk', regardless of age. The tension between the approaches of visible or hidden hip protection discussed in section 4.5 (where it is difficult for new products to challenge ageist attitudes if people are not visibly seen to be engaging with them) is also somewhat eased. The hip vest concept could be worn both visibly or under clothing, with the hip pads tucked in or layered over clothing. This gives the wearer agency to decide in what contexts the garment might be visible or hidden. When discretion is important, the hip vest concept could also manifest the kind of *quiet* empowerment described earlier, that embraces a pro-active, yet understated, approach to living and ageing well.

5.4 Prototyping, testing and evaluation

This final stage of the research culminated in hip vest prototypes that could be tested to demonstrate proof of concept. This included mechanical impact testing of hip pad designs to evaluate their energy absorbing capability, and participants (recruited from the student population at low risk of falls) wearing the hip vest garment to evaluate the aesthetics, comfort, and ease of use. Product user evaluation also involved a workshop to review the hip vest design in the context of the five personas established earlier through the research. These processes build on the earlier design development, engaging with the principles of Action Research, to refine the design outcomes. The findings established through this stage of testing and evaluation have informed design proposals that represent the 'develop' and 'deliver' phases of the Design Council's Double Diamond.

5.4.1 Mechanical impact testing

The potential for flexible 3D printed lattice hip protection has already been established (see 5.2.1.3 and 5.3.3) In particular, the opportunity for energy absorbing surfaces that could be thinner and

more discreet than current hip protector pads. To establish the viability of these materials to reduce the risk of hip fractures in the event of a fall, I designed and manufactured a drop test rig to measure the impact attenuation properties of the test pieces that were being developed. The intention was to demonstrate proof of concept of flexible 3D printed lattice materials by comparing their effectiveness to commercially available hip protectors. The investigation focused on producing a hip pad that reduced impact energies below the 2.5kN threshold that can cause a femoral fracture (Mills 1996), whilst maintaining a profile thickness slimmer than existing pads.

5.4.1.1 Methodology

There are several descriptions in the literature for mechanical test systems used to measure the peak force absorbed by hip protector pads during a simulated fall (Robinovitch et al. 2009). For example, the International Hip Protector Research Group (IHPRG) recommend using an effective falling mass of 28kg (range 22-33kg) with a vertical drop tower or curved path pendulum system, and an impact velocity of 3.4m/s. To simulate the compressive stiffness of the pelvis they also recommend including a 47kN/m (range 39-55kN) parallel spring-damper support (Robinovitch et al. 2009). Derler et al. (2005) investigated 5kg, 10kg and 15kg as effective falling mass onto an anatomical hip model that allowed for the realistic positioning of hip protectors on the body and the tri-axial measurement of forces on the femoral neck. The test rig I used followed the approaches adopted by Wardiningsih and Troynikov (2019) and Yahaya et al. (2021) who explored the impact attenuation of hip protector pads using a 5kg effective falling mass. In the latter study, the authors also investigated the capability of 3D printed hip protectors in a simulated sideways fall, although they tested a rigid 3D printed part. Both studies used a vertical drop tower but neither incorporated a spring-damper support to simulate pelvis stiffness. Yahaya et al. (2021) rejected the use of a spring fixture, “since the articulation of the hip of an elderly person may lack the elastic properties represented by a spring constant”. Regardless of their view, I also did not incorporate a spring-damper arrangement but this was mainly due to a limited budget for accessing or developing impact testing equipment. Yahaya et al. (2021) also used an aluminium surrogate femur, but resource constraints meant I opted for Wardiningsih and Troynikov's (2019) simpler approach of a 5mm steel plate covered by a silicon layer to simulate the greater trochanter and surrounding soft body tissue. This less sophisticated approach to the mechanical test system design is a limitation to the study.

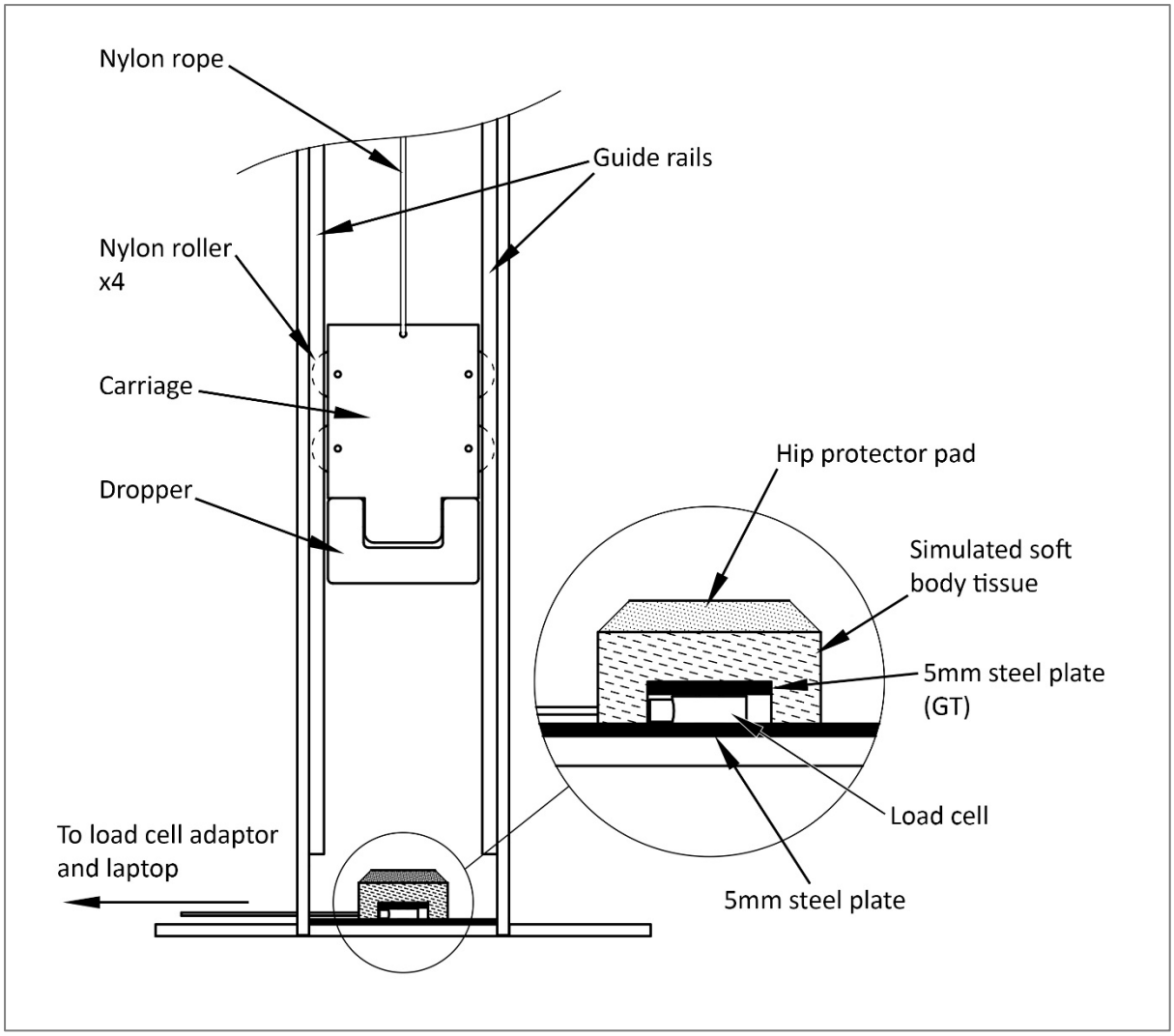


Figure 98: Graphical representation of the drop test rig.

The drop test rig (see Figure 98) consisted of a 5.3kg steel weight with a uniform underside surface, that acted as an impact plate to simulate hitting the floor. Ideally, a dropper weighing exactly 5kg would have been used to replicate the approach of Wardiningsih and Troynikov (2019) and Yahaya et al. (2021). However, the dropper available to use with the test rig, weighing 5.3kg, was deemed an acceptable compromise. The dropper was fixed below a carriage with four nylon rollers allowing it to fall freely between two vertical guide rails. The dropper and carriage assembly were suspended on a nylon rope that ran over a pulley at the top of the tower. This allowed the dropper to be lifted to a predetermined height and released using a simple stopper mechanism.

At the base of the tower, directly below the suspended dropper, a 20kN capacity 410 Series miniature button load cell (Load Cell Shop 2024a) was firmly screwed to a 5mm thick mild steel plate. The load cell was linked to a 4.8kHz DSC USB load cell adapter (Load Cell Shop 2024b) that connected

to a Dell Latitude 3580 laptop running FSU toolkit software (Mantracourt 2024) to record and review the impact force data.

The 5mm thick mild steel plate, 50 x 50mm, was positioned on the top side of the load cell. This was to simulate the greater trochanter with the size derived from the 50mm diameter of the average female femur head (Mall et al. 2000; Derler et al. 2005). A square, soft silicon housing was cast to fit over the top of the load cell and metal plate. This simulated the soft body tissue over the greater trochanter and, with a shore A hardness of 12, had the same properties as the artificial flesh used in other impact testing of hip protectors (Derler et al. 2005). The thickness of the silicon above the metal plate was 20mm, as this corresponds to the typical thickness of the soft tissue over the femur head in female hip fracture patients (Lauritzen and Askegaard 1992).

I derived the methods for calculating fall speed, impact energy, and force attenuation of the hip protector pads, from Wardiningsih and Troynikov's (2019) study. The authors cited Robinovitch et al. (2009) who observed that typical fall speeds are 2m/s for a “mild fall”, 3.4m/s for a “moderate fall”, and 4.5m/s for a “severe fall”. The kinematic equation for free fall is:

$$V^2 = 2gh$$

where V is the speed (m/s), g is gravity (m/s^2), and h is the height (m). The authors then rearranged the equation as follows:

$$h = \frac{V^2}{2g}$$

From this equation, the fall speeds at 2m/s, 3.4m/s, and 4.5m/s, correspond to a dropper height of 0.2m, 0.6m, and 1m respectively. The drop test tower was built to accommodate these drop heights. The impact energy generated by the 5.3kg dropper when dropped from the three heights can be calculated using the equation:

$$E = mgh$$

where E is the impact energy (J), m is the mass (kg) and h is the height (m). The impact energies are calculated as $E_{0.2m}$ = 10.4J, $E_{0.6m}$ = 31.2J and E_{1m} = 52J.

Five drops were conducted for each test condition, with a 3 minute time interval between each to allow any temporary deformation in the pad or simulated soft tissue to ease (Robinovitch et al. 2009; Wardiningsih and Troynikov 2019). The peak impact force (kN) was recorded using the FSU Toolkit software (Mantracourt 2024) and the mean and standard deviation of the five test results for each test condition were calculated.

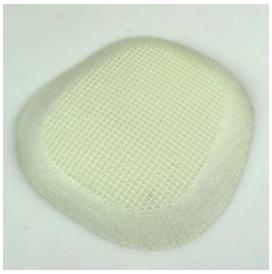
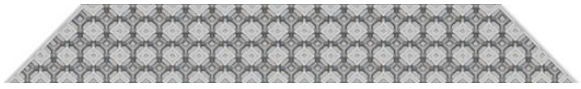
To compare the impact energies occurring at the greater trochanter in conditions with and without a hip protector pad, the dropper was dropped onto the 'unprotected' simulated soft body tissue. In the drop test, at a height of 0.6m, the mean impact force was 4.2kN (SD 0.3). This is well above the 2.5kN force required to fracture the femoral neck of an older female (Mills 1996), and could well meet the force required for a male fracture at the upper end of the standard deviation range (Robinovitch et al. 2009). As a drop height of 0.6m simulated high risk of a fracture, for convenience this was kept as the default height to test the range of hip protector pads, prototype pad and test pieces. To test their impact attenuation ability, the percentage impact attenuation rate was defined as follows (Keenan and Evans 2019):

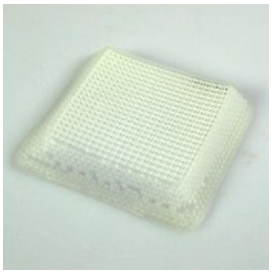
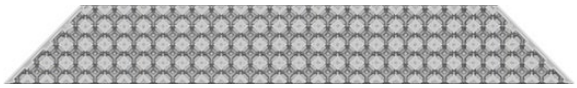
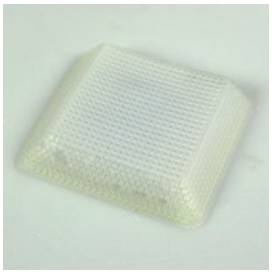
$$\%\ Impact\ Attenuation = \left(1 - \frac{F_u}{F_p}\right) \times 100$$

where F_u is the impact force on the 'unprotected' simulated soft body tissue and F_p is the impact force recorded by the load cell when the hip protector pad is placed on top of the simulated soft body tissue.

Table 22 shows the range of tests conducted to compare the peak impact forces and percentage force attenuation. LHP004 was developed to prove that a full-size 3D printed pad could be produced on the Formlabs Form 3 machine. Following the principles of Action Research, the LHP004 prototype, Fall Safe, and HiP pads were tested first to compare their performance, then the findings informed the development of 1106, 1107 and 1108 hip pad test pieces, which were tested later. Similarly, the review of these later samples then informed the 1110 Hip Pad Test, which led to the final iteration of the pad design.

Table 22: Range of hip protector pads tested to compare peak impact forces and percentage force attenuation.

Hip protector pad or test piece	Description	Material	Cell size (mm)	Beam thick-ness (mm)	Part thick-ness (mm)
Fall Safe	Pad from Fall Safe underwear hip protector garment.	Polyurethane blended with dilatant (PBDMS)	N/A	N/A	18.5
HiP	Pad (integrated) from HiP hip protector garment worn over clothing.	Open cell urethane foam	N/A	N/A	6
LHP004 	Full-size 3D printed lattice hip pad 151x170x12.8mm. Formed to fit prototype vest produced by DM Orthotics. Kelvin lattice structure is open on both sides.	Formlabs Flexible 80A	4x4x4	0.8	12.8
1106 Hip Pad Test 	95x85x12mm test piece. 0.8mm wall thickness. Chamfered on three faces to reflect intended detailing on full-size prototype. Lattice open on both sides.	Formlabs Flexible 80A	4x4x4	0.8	12

Hip protector pad or test piece	Description	Material	Cell size (mm)	Beam thick-ness (mm)	Part thick-ness (mm)
1107 Hip Pad Test  	95x85x12mm test piece. 0.8mm wall thickness. Cell size reduced to accommodate four layers within the 12mm height. To explore effect of reduced cell size on force attenuation.	Formlabs Flexible 80A	3x3x3	0.6	12
1108 Hip Pad Test 	95x85x12mm test piece. 0.8mm wall thickness. Kelvin cell with vertically-graded beam thickness. To mimic the properties of the skin of the pomelo fruit (an impact absorbing example from nature) that has a hierarchical organisation of cells (AskNature 2016).	Formlabs Flexible 80A	3x3x3	1mm at top surface uniformly decreasing to 0.6mm at the lower surface	12
1110 Hip Pad Test	95x85x9mm test piece. 0.8mm wall thickness. Takes the cell geometry from 1107 but with one layer removed. With three layers, the height is reduced to 9mm. To explore effect of reducing part thickness on force attenuation.	Formlabs Flexible 80A	3x3x3	0.6	9

5.4.1.2 Results and discussion

Figure 99 shows the mean peak impact forces measured by the load cell under 31.2J of applied energy resulting from dropping the 5.3kg dropper at 0.6m height. The results across the seven tests are shown alongside the mean impact energy recorded when no pad was in place and the dropper contacted directly with the simulated soft tissue. The 2.5kN force threshold is also indicated demonstrating that the HiP hip protector belt would be the least effective at preventing a fractured hip. All the flexible 3D printed lattice samples reduced the impact force to below the 2.5kN threshold, with LHP004 demonstrating the best performance. The prototype also outperformed both the commercially available hip protector pads.

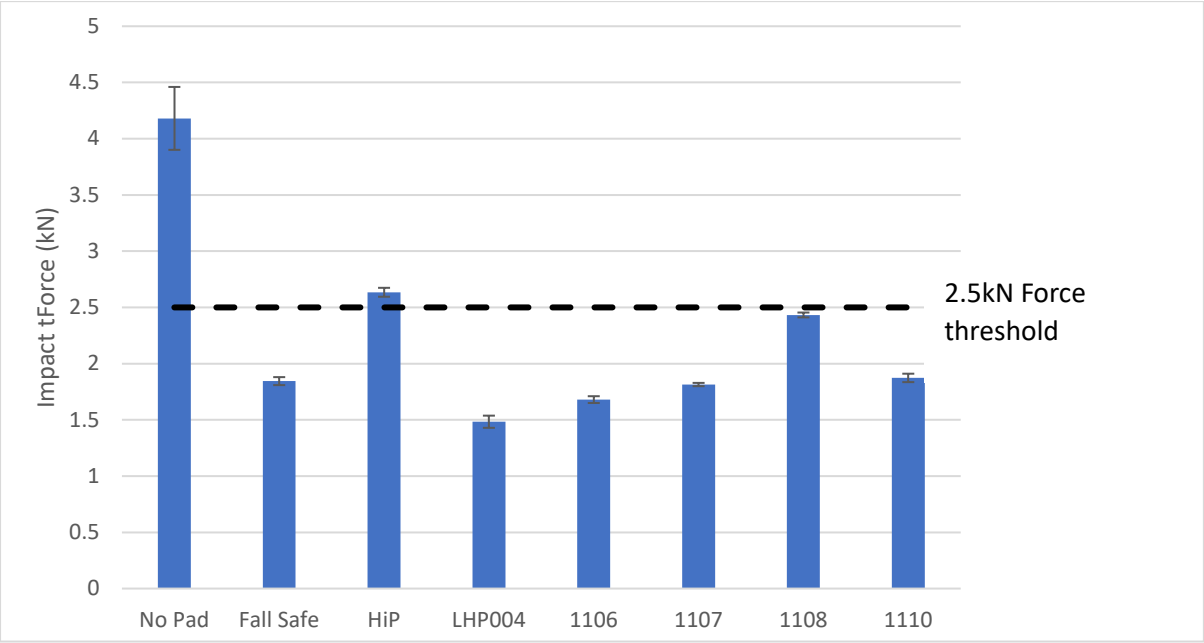


Figure 99: Mean impact forces measured with no pad, hip protector pads, prototype, and test pieces, when 31.2J of energy is applied.

Table 23 shows data for the test samples in order of highest to lowest impact attenuation. It is important to recognise the lack of spring-damper support to allow for the compressive stiffness of the pelvis. Robinovitch et al. (2009) note that an overly stiff system will overestimate the reduction in peak force provided by a hip protector pad. This could account for the comparatively higher levels of impact attenuation on the best performing samples compared to those studied by Laing et al. (2011) (see Appendix C – e.g. HipEase 40% impact attenuation a 3m/s fall speed) who followed the IHPRG recommendations for mechanical test system design. Nevertheless, the tests I conducted

provide a useful performance comparison between the prototypes, test pieces, and commercially available pads under consistent test conditions.

Although the cell geometry in LHP004 and 1106 is almost identical, the LHP004 prototype pad demonstrated about 5% higher impact attenuation. This is likely to be due to the larger footprint of LHP004 compared to the test piece, where more of the impact energy can be absorbed laterally across the body of the pad. Reducing the Kelvin cell size from 4x4x4mm in the 1106 test piece to 3x3x3mm in the 1107 test piece appeared to slightly reduce its energy absorbing effectiveness. However, its performance is still comparable to the Fall Safe hip pad, yet it is over 6mm thinner.

Table 23: Hip protector pads and test pieces ranked in order of impact attenuation.

Hip protector pad or test piece	Thickness (mm)	Mean impact force (kN)	Standard deviation	Impact attenuation (%)
LHP004	12.8	1.48	0.05	64.5
1106	12	1.68	0.03	59.8
1107	12	1.81	0.01	56.6
Fall Safe	18.5	1.84	0.04	54.5
1110	9	1.87	0.03	53.8
1108	12	2.43	0.02	41.8
HiP	6	2.63	0.04	37.0

Although vertically-graded lattice structures are shown to have better energy absorbing performance compared to uniform lattices (Habib 2020; Dwyer et al. 2023), this was not found to be the case with the 1108 test piece. This may be due to the overall pad thickness of 12mm not being sufficient for the graded lattice to make any significant difference (Habib (2020) and Dwyer et al. (2023) both tested 25mm thick samples, for example). The result may also be due to densification of the lattice structure towards the base of the 1108 test piece where the beam thickness is 0.6mm. Densification is when the applied force is enough to completely flatten the lattice, so it acts like a solid, reducing its energy absorbing capability (Dwyer et al. 2023). Further research is needed to explore the potential for greater impact attenuation using vertically-graded lattice structures in smaller pad thicknesses.

The final test piece, 1110, is over half the thickness of the Fall Safe pad but demonstrates equivalent levels of impact attenuation. This is an encouraging result, challenging the findings by Laing et al. (2011) that the thicker the hip protector pad, the greater the level of impact attenuation. At 9mm thick, the 1110 test piece has provided proof of concept for a thinner, more discrete type of hip protector pad. This has formed the basis for a pad design to be integrated into the hip vest concept.

5.4.1.3 Implications for 3D printed hip pad design

The mechanical impact test results demonstrate the potential of flexible 3D printed lattice structures for hip protector pads. The findings show that a 9mm thick pad with a 3x3x3mm Kelvin cell structure would be capable of preventing a hip fracture at a moderate fall speed of 3.4m/s. Potentially, even thinner pads could be developed but reflecting on feedback from users (see 4.5), it is important that hip protectors evoke confidence and are perceived to be effective. For example, a participant in the female focus group (see 4.2.2) was concerned that the HiP padded belt (with 6mm thick pad) didn't look resilient enough to protector her. Reflecting on the mechanical impact testing, her concern appears to be justified.

Figure 100: LHP005 flexible 3D printed lattice hip pad prototype. Kelvin cell lattice geometry based on 1110 test piece.

Informed by the lattice geometry and overall part thickness of the 1110 test piece, I developed the LHP005 prototype (see Figure 100). This was produced using the same methods described in 5.3.3.2 and 5.3.3.3 and printed in Flexible 80A resin on the Formlabs Form 3 printer. The centre portion of the pad has a thickness of 9mm, but this tapers down to 0.6mm around the outside edge of the pad.

Unlike LHP004, this was an attempt to create a more blended appearance between the pad and the wearer's body. On the first build attempt a small section on the left hand edge of the pad failed, although this issue was later rectified by adding more support material to this area. This, and other challenges relating to the LHP005 are discussed in more detail later (see 5.4.3.1).

Further investigation into the performance of the 3D printed lattices at higher fall speeds (simulating a 'severe fall' at 4.5m/s) is needed but this is beyond the scope of this study. It is recommended that higher speed impact tests are conducted under scientific conditions where other variables can also be considered, including simulating the compressive stiffness of the pelvis. Similarly, how the material performs at different temperatures relating to the environment of use, and any discrepancies between when the wearer first puts on the hip protector and after the pad has had time to warm up to body temperature. Additionally, what the implications might be for material performance over a period time, including repeated impacts, or if the pads were put in a washing machine (accidently or not). These further areas of investigation demonstrate the limitations of the mechanical impact testing conducted for this research and establish key questions that would need to be addressed before flexible 3D printed lattice hip protector pads could be commercialised.

5.4.2 Product user evaluation

Throughout the design process, I was able to trial prototype garments to evaluate their overall comfort and wearability. This was a critical part of the iterative development of concepts and engagement with Action Research. Indeed, one key aspect of the vest design that evolved from the early prototypes was an increase in length at the back of the garment, so the rear hem sits lower over the wearer's bottom. This was to help keep the pads in a stable position. For further trials, silicon-backed fabric was applied to the inside panels behind the hip pads. The silicon has a soft but grippy texture to help keep the pads in place. The refinements to the vest design are discussed in more detail later (see 5.4.3.2).

It was also important to gain further insight into the experience of wearing the hip vest from other users. This section discusses the product user evaluation with participants invited from Falmouth University's undergraduate population. The students were chosen to overcome the constraints set by the UAL Research Ethics Sub-Committee (RESC) of not allowing older, more vulnerable people to wear prototypes (see 3.6). As the students were studying on the BA(Hons) Sustainable Product Design course, they were also able to critically reflect on the prototypes from an inclusive design

perspective. This insight was particularly helpful during the second stage of product user evaluation which culminated in a persona workshop to evaluate the hip vest prototypes with reference to the five personas established earlier on.

5.4.2.1 Methodology

A convenience group of four participants (two women and two men) were selected who had all recently completed a 30-credit undergraduate module on inclusive design. This equipped them with an understanding of human-centred design research methods and an awareness of how designed products often overlook the needs of older users with mobility or dexterity issues. Tang (2010) also notes the advantages of engaging design students in PhD research activity. The participants selected had good physical fitness and mobility and were not at risk of falls or fragility fractures. In advance of the activity, participants were individually measured by a trained staff member at DM Orthotics and a prototype garment was manufactured for them to use (see Figure 101). Four participants were chosen as a reasonable number of prototypes for DM Orthotics to produce.

Figure 101: Example prototype hip vest garment manufactured by DM Orthotics.

Testing of the efficacy of impact protection with users was not part of this research, and it was important this was clear to participants from a research ethics perspective. Instead, prototype garments under review contained 'dummy' EVA foam hip pads to represent the 9mm material thickness (see Figure 102). This provided minimal impact protection, which participants were made aware of through the participant information form and verbal briefing, in advance of the activity. The disadvantage of this approach was that the pads had a distinct protruding edge (the outline can be seen in Figure 101), unlike the tapered edges of the LHP005 prototype designed to blend into the hip surface. The dummy pads are also slightly larger because the LHP005 prototype was pressed flat against the foam to draw the profile to be cut. On reflection, it would have been better to create a separate card template.

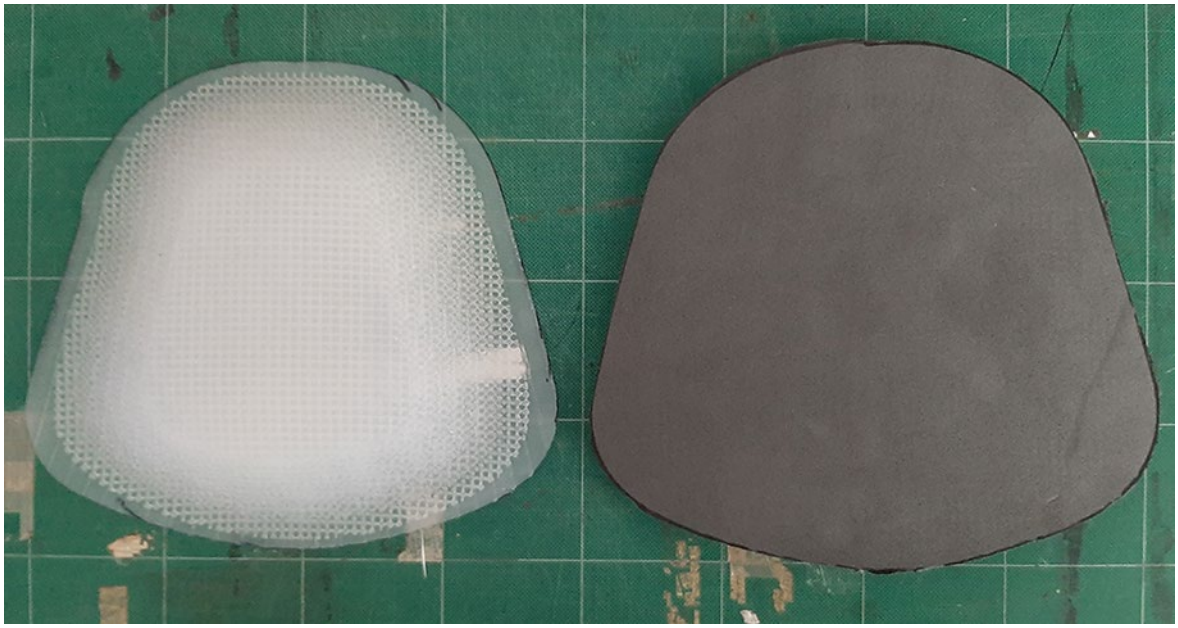


Figure 102: LHP005 prototype used as a template to cut the dummy pad from 9mm EVA foam.

Participants were asked to wear the garment for a full day and record their observations. They could wear whatever clothing they were comfortable in over the top of the prototype garment. A feedback form (see Appendix P) allowed them to describe their experience at specific points during the day: in the morning (putting on), during the day (wearability relating to walking, sitting, standing, etc), and in the evening (taking off). They were asked to complete the form ‘in the moment’ where possible, or at least on the same day whilst the experience of wearing the prototype was fresh in their minds.

Once the garment was on and they were ready for the day, they were asked to take one photograph of themselves in the mirror to record what they were wearing and their outward appearance (with

the prototype garment completely hidden under their outer clothing layer). This was to review the different clothing choices and discuss how these may have been influenced by having to wear the prototype garment underneath.

After they completed the activity, a follow up focus group took place where participants shared their experience of wearing the prototype garment and discussed opportunities for improvements to the design. The participants used Post-It notes to jot down perceived strengths and weaknesses in the prototype as they were discussed and note any further design opportunities. A workshop took place shortly after the focus group where the participants mapped their own experiences of wearing the prototype to how they felt the five personas would perceive the experience. This included considering how their own perceptions previously shared on Post-It notes may affect the personas (see 4.4) to establish further ways the design could be developed and improved.

The focus group and persona workshop were documented using a Zoom H4n portable audio recorder and video recordings were also made using a Panasonic HDC-SD60 Camcorder mounted on a tripod in the corner of the room.

5.4.2.2 Focus group discussion

All four participants returned their feedback form in advance of the focus group discussion. This allowed some time to review their experiences of trialling the vest beforehand. Many of the issues discussed in the earlier interviews (see 5.3.2) were reflected in this evaluation process and later in the persona workshop.

Participant 1 wore the vest for 4.5 hours, participants 3 and 4 wore it for about 13 hours, and Participant 2 wore if for over 18 hours. The questions on the feedback form provided the basis for the discussion which followed the logical order of experience of putting the garment on, wearing it throughout the day, and taking it off. Their overall impressions of the garment, in terms of comfort, ease-of-use, and appearance, provided an encouraging starting point (see Figure 103). The lower score on appearance from Participant 1 was explained by the comparative bulkiness of the foam pads used for the trial. However, it was clear through the discussion that there were other opportunities to improve the design.

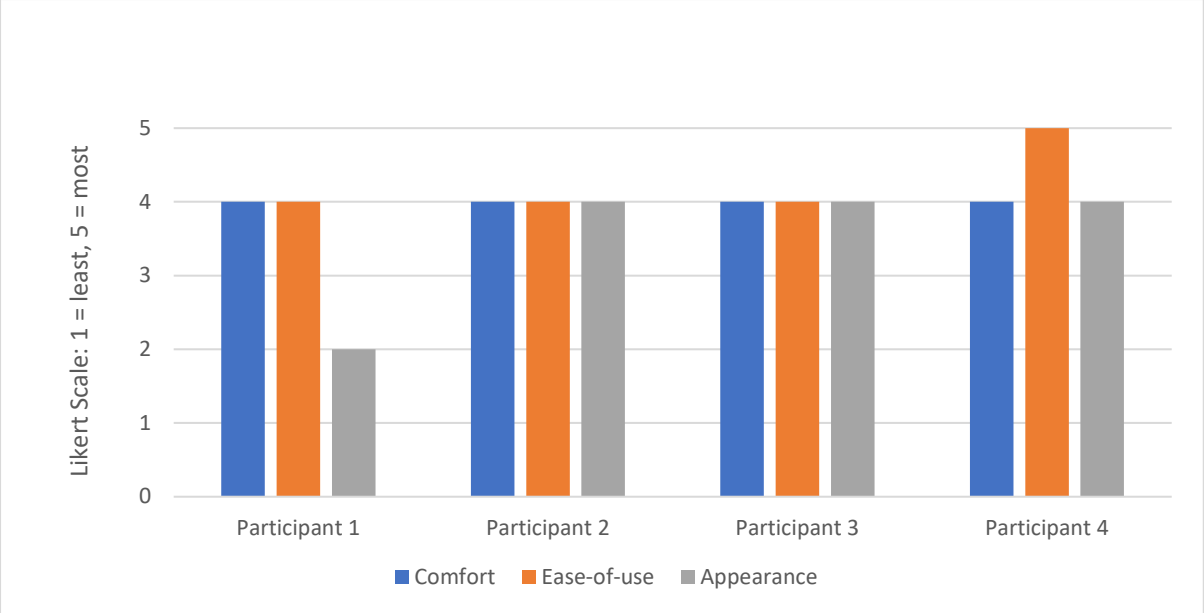


Figure 103: Participant evaluation of the vest in terms of comfort, ease-of-use, and appearance, using 1-5 Likert scale.

None of the participants struggled to put the garment on, but there were some frustrations noted due to the extra length of the vest and the positioning of the foam pads. One participant noted that it was awkward to pull over their head with the pads on either side. The issue of the pads being pushed up the body when pulling on trousers was also discussed, with the need to tuck them back down over the hips. This problem may have been exacerbated by the comparative bulk of the foam pads that, without a tapered edge, are more likely to snag on trousers as they are pulled up to the waist. The foam pads are considerably stiffer than the flexible 3D printed lattice hip pads, which must also be recognised as part of this evaluation. The potential to wear the pads so they are visibly layered over clothing was not investigated here because the earlier research demonstrates a greater preference for hidden pads. This approach would make adjusting the pads more accessible but potentially mean higher risk of the pads moving out of position.

DM Orthotics mostly manufacture compression garments where the seams are placed on the outside for greater comfort. The prototypes were produced using the factory's standard sewing machine set-up, so these too had the seams on the outside. This caused some confusion for the participants in terms of how to orientate the garment, especially as they were also without the usual branding or care label on the inside of the collar to indicate which way round to put it on. These are important signifiers of cultural norms of clothing that should not be overlooked.

Wearing the garment did influence the clothing the participants chose to wear over the top. Three of the participants opted for clothing that would help to disguise the pads. For example, after trying on jeans, one of the participants chose instead to wear a loose fitting skirt, and another opted for a

longer jumper to hide the shape of the pads. Although three participants commented on feeling self-conscious about the pads making their hips appear to be bigger, they were all sure that no-one else had noticed and no-one had commented on their appearance. The photographs the participants took of themselves whilst wearing the vest (see Figure 104) demonstrate that the appearance of the foam pads is negligible.

Figure 104: The participants wearing the hip vest under their clothing on the day of evaluation (photographed by the participants).

No other reasons for clothing choices were noted but the potential for overheating in hotter weather was discussed during the focus group. The evaluation took place during mild spring weather, but only physical exertion from running or cycling, noted by two participants, caused them to feel too hot. All the participants spoke positively of the feeling of the vest once it was on. In particular, the softness of the fabric and its close fitting providing a sense of warmth and security. Three participants reflected on not noticing the pads as much once they became used to them.

The participants described the activities they undertook during the day, and this was discussed further during the focus group. In addition to the participants who had run and cycled, they had all spent some time both sitting and walking, and engaging with other activities such as cooking, cleaning, or working at a computer.

When sitting down, the participants wearing trousers or shorts found the vest comfortable. One noted that, “I usually forgot that I was wearing it at all”. Another commented that the pads wrapped around her hips, “so it felt as if I was sat on the bottom edges of them, but this wasn’t uncomfortable”. However, the participant wearing a skirt noted that she was more aware of the pads when sitting because they would ride up, with the bottom of the pad resting on the chair surface and

the top pushing closer towards her waist. Conversely, when standing and walking she found it more comfortable, noting that she often almost forgot she was wearing the vest. Notwithstanding the comparative stiffness of the foam pads, this may indicate that wearing trousers (or at least clothing with a closer fit to the hips and crotch) helps to stabilise the pad position when sitting. This could have implications for the types of clothing recommended to wear with the vest.

All the participants needed to re-position the pads at various times throughout the day. This was generally reported when changing position, for example from sitting to standing, or after using the toilet. Adjusting the pads in public was also an issue noted by two of the participants. Participant 1, who wore a skirt, reported adjusting the pads 10 to 15 times during her 4.5 hours of wearing time. The other female participant, however, who wore the vest for 13 hours under trousers with a belt, only needed to adjust the pads "once or twice" after using the toilet. This further demonstrates how the pad stability could be contingent on the clothes worn over the top.

To assist with pad stability, the prototypes had an area of silicon-backed fabric on the inside surface where the pads contact with the wearer's hip. However, one participant was particularly put off by the silicon material and the "cringy" feeling against bare skin. He also commented that when needing to re-adjust the pad position, "the sticky, plastic, rubber grips were too effective", noting it was difficult to discretely move the pads under his trousers. The value of the silicon-backed fabric needs further investigation. A further concern, prompted by these comments, is the danger of the sheer forces between the silicon and the wearer's hip which could damage fragile skin, especially in older users.

A final important observation when wearing the garment (noted by two participants) was how the pads impeded access to trouser pockets. Again, the comparative bulkiness of the foam pads compared to the flexible 3D printed design could have made this issue more pronounced. This may be difficult to overcome when wearing close fitting garments over hip protector pads. It could be especially problematic for women where garment pocket sizes already tend to be much smaller than in menswear. Notably, I have not seen this problem discussed in any of the literature on the design of hip protectors.

No major issues were raised relating to removing the garment. Both the female participants felt it was easier to take off than to put on as they did not have to worry about the pad positioning. One of the male participants struggled more than he expected he would due to the stretchy fabric (the four way stretch direction in the fabric used may have compounded this) and the grip of the silicon-backed fabric. During the focus group, the ease of putting on or taking off the garment for someone

with mobility difficulties was raised as a potential area of concern. This issue was explored further through the persona workshop that followed.

The focus group provided some key areas for improvement to the vest prototype. The discussion led to suggestions for further design development, summarised as:

- Hip pad stability – include leotard fastening (Velcro or snap-poppers) in the crotch, although this could impact on ease of use. Alternatively, underwear shorts designed to be used with the vest could locate over the hip pads, or fasten with Velcro, to keep them in place. Both these solutions could negate the use of silicon-backed fabric, overcoming the issues reported with this material.
- Ease to put on and take off – suggestion for side opening on the garment with a zip or Velcro. Stepping into the garment and pulling up was also discussed as an alternative way of getting into it.
- Access to pockets – the same issue could be found with other types of hip protectors. Potential for an overwear belt concept with an integrated pocket (as discussed in 5.2.1).

5.4.2.3 Persona workshop

Along with their reflection on wearing the hip vest prototype, the participants engaged with the suggestions for design development whilst considering how the five personas (see 4.4), Emma, Wendy, Delores, Greta, and Nancy, would perceive and use the garment. An interactive discussion unfolded where issues and design opportunities previously written on Post-It notes during the focus group were mapped against the relevant personas. Further ideas were expanded through notes and annotations written below each persona (see Figure 105).

The participants chose to begin the discussion with Wendy, a 54 year old woman who is married with two grown-up children, and Delores, a recently retired 66 year old who lives on her own (see Figure 106). Although both personas are in earlier life phases, their personalities and lifestyles differ considerably. Wendy's apparent focus on style and aesthetics, and desire for "prettier" hip protectors, immediately prompted the suggestion that black should not be the only colour option. This resonates with the discussion on colours during the earlier hip vest feedback interviews (see 5.3.2).

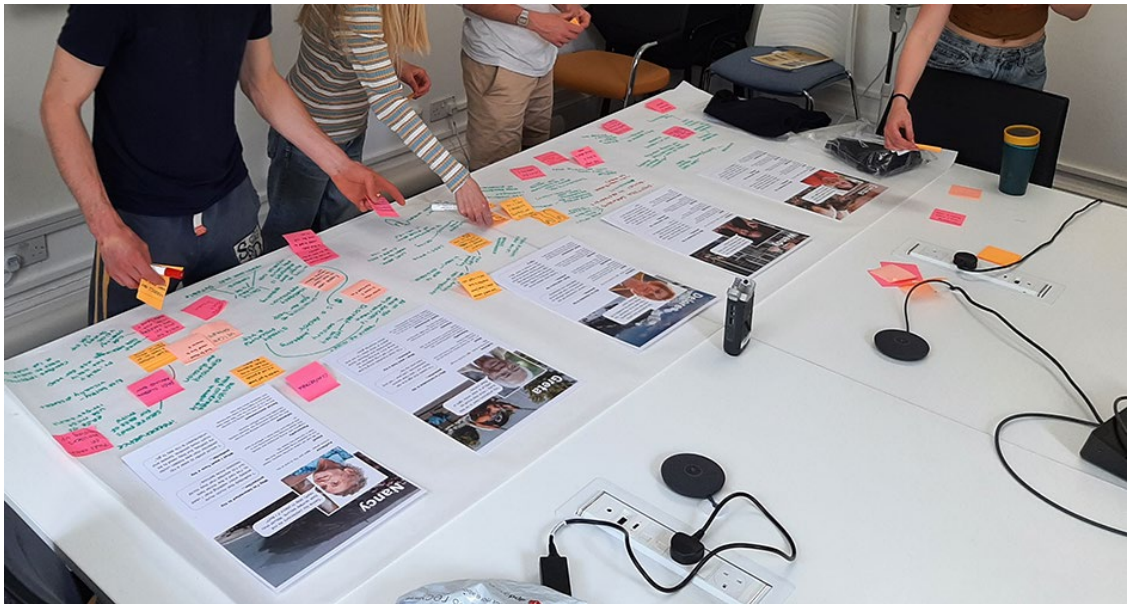


Figure 105: Persona workshop with student participants.

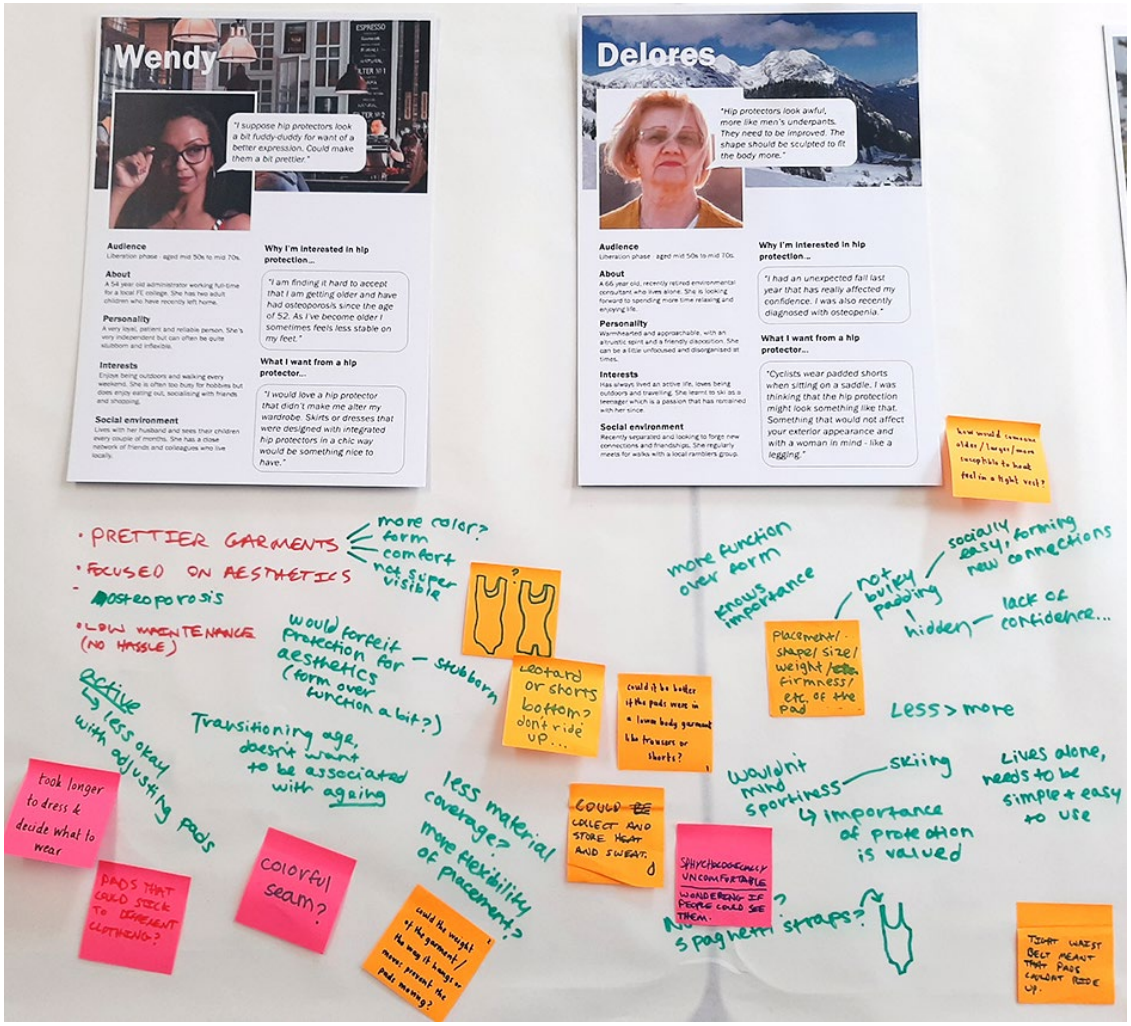


Figure 106: Evaluating the hip vest prototype through the personas Wendy and Delores.

It was noted that Wendy's notion of skirts or dresses with integrated hip protection could reflect her resistance to the idea of getting older. Although not wanting to have to alter her wardrobe seems contradictory, the participants considered that she may be put off by having to wear a separate hip protector garment that didn't meet her style expectations. This was coupled with the idea that Wendy's busy lifestyle would mean that she wouldn't want the hassle of dealing with a separate garment. In addition to the colour, the participants also discussed other aspects of the vest style for Wendy. Her photograph depicts her in a top with straps, prompting whether she would prefer less coverage and thinner straps to the vest. This was countered by her enjoyment of the outdoors and weekend walks, where a sporty aesthetic (and wider straps) could be more acceptable. A discussion on when Wendy would wear the hip vest led to agreement that, due to her being a younger and less vulnerable persona, higher risk activities, such as exercising would be the most likely scenario. The participants noted from their own experience that more movement and activity can lead to the pads needing re-adjustment more often, which Wendy could find frustrating. The idea of a leotard style garment was suggested as an alternative in this case, with breathable fabric to wick away sweat when exercising. Overall, it was noted that Wendy's tendency to be inflexible would mean that if the garment didn't fulfil her needs, practically and aesthetically, then she wouldn't put up with it.

Delores' sporty lifestyle was seen to align more obviously with the hip vest design. The issue of hip pad stability discussed for Wendy can be equally applied. Her need for hip protection that is more flattering and sculpted to the body was also discussed. Her social situation finds her meeting new people and forging new relationships, whilst also lacking confidence due to her fall. This could make her feel more self-conscious about her appearance so hidden hip protection that is comfortable to wear is critical. This aligns well with the approach for LHP005 where the low profile hip pad has tapered edges to blend with the hip surface.

Assuming it could be worn discretely, the participants felt that Delores was more concerned with the protective qualities of the garment than its appearance. This prompted the suggestion that Delores might simply prefer an underwear hip protector. As she lives alone, it is important that the garment is easy to put on and take off without requiring help. Overall, her recent experience of a fall and awareness of protective clothing in sports were considered to be high motivational factors to engage with hip protection. However, like Wendy, the participants felt this would only be in the context of higher risk activities.

The participants continued the evaluation by discussing Greta, a 77 year old retired teacher living with her husband, and Nancy, an 88 year old widow who has recently moved into an assisted living apartment (see Figure 107). Greta is in the 'summing up' phase, finding meaning in her life with an

urge to share her wisdom. Nancy is in the 'encore' phase, reflecting and reaffirming her major life themes, and living well to the end (Cohen 2006).

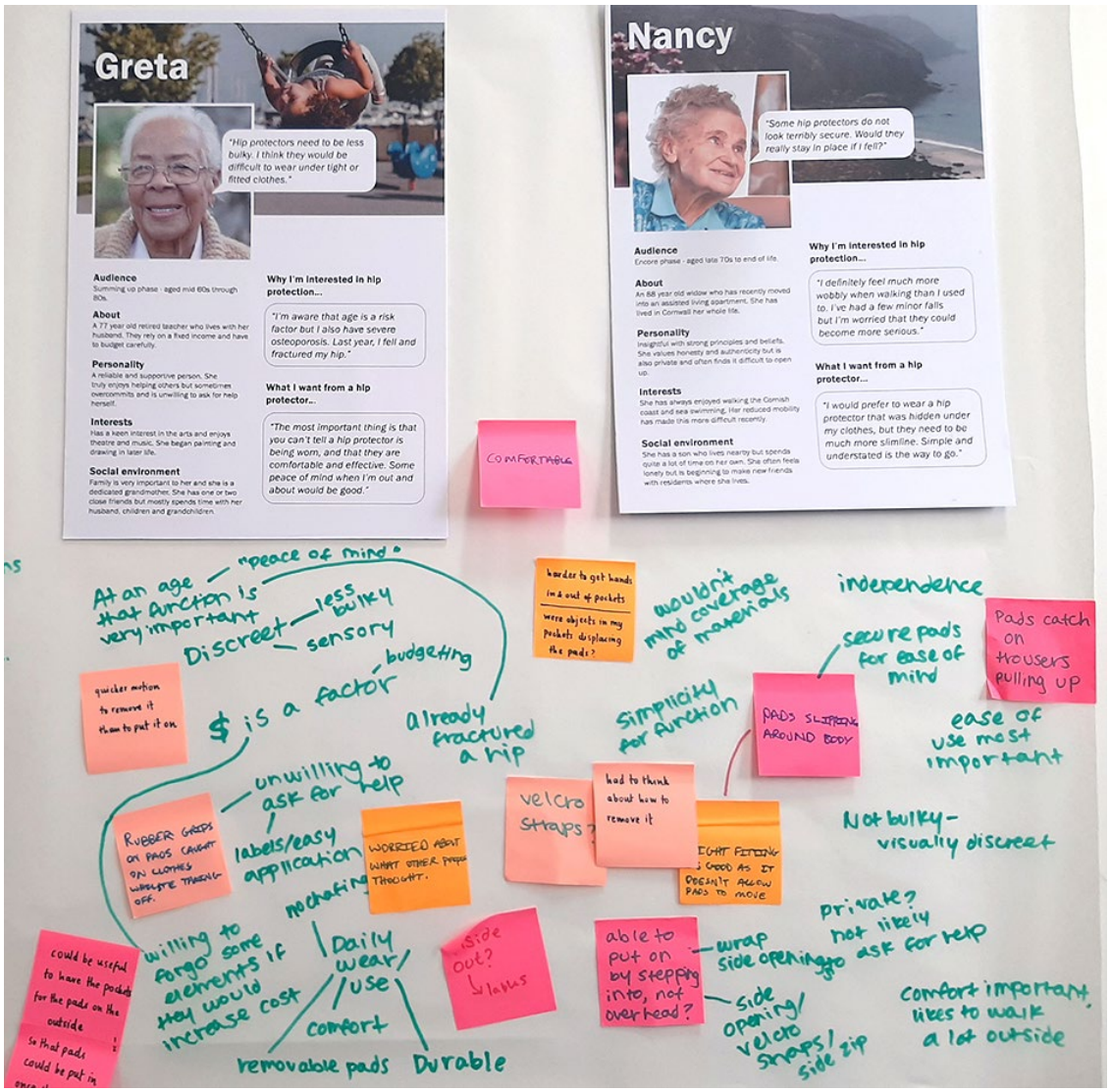


Figure 107: Evaluating the hip vest prototype through the personas Greta and Nancy.

For Greta, the experience of already fracturing her hip reinforces the value of wearing hip protection. This informed the view that the effectiveness of the garment was a key priority for her. The participants noted her need for "peace of mind" and recognised that she might wear the hip vest more frequently than Wendy and Delores. In this case, comfort is prioritised but still not at the risk of the garment being visible when worn. It was noted that Greta is less active than Wendy and Delores which prompted a discussion about comfort when sitting down, reflecting on the feeling of the pads riding up whilst seated. The idea of the garment being both visually discreet but also *sensorily*

discreet was an interesting concept to emerge and aligns with the earlier discussion on phenomenology (see 2.1.3). If Greta were to wear the garment every day, she would need more than one, and it would require regular washing. The participants discussed the durability of the garment in this respect, and the need for easily removable hip pads.

With Greta's fixed income, it was suggested that she may have to think more practically about clothing compared to Wendy and Delores. This could mean forgoing a more visually appealing garment if a simpler version was cheaper, especially if she needs to buy more than one. Functional aspects cannot be overlooked, however. At an age where she may be losing mobility it is important that the garment is easy to put on and take off. Her unwillingness to ask others for help also reinforced the need for ease of use. The earlier observation that a label in the neck of the garment immediately communicates its orientation was noted again.

Nancy is the oldest persona and the participants recognised that her reduced mobility means that getting the vest on and off easily was very important. Living alone, she doesn't have anyone to help her dress. Although she lives in an assisted living apartment, support with an intimate garment like the vest might overstep her private nature. The discussion led to whether Nancy would struggle getting the vest over her head, and perhaps being put off if she was afraid of getting stuck in it. A wrap garment style was considered a better option, with a side opening zip being more discreet and less bulky than an opening down the front. However, caution is needed specifying fiddly zips appropriate to hand strength and dexterity. The participants also discussed the difficulties Nancy might have to remove the pads before washing the garment. As eyesight deteriorates with age, she may struggle to find the opening to the pad pocket or have the strength or dexterity to remove the pad. These are important considerations for users with impaired vision or mobility.

Nancy is concerned about the hip pads staying in place if she were to fall. This was perceived as a need for the garment to look robust so she will feel safe in it. It was suggested that thicker straps and more material might provide greater reassurance, although she does suggest that she would prefer something more slimline. The participants felt that Nancy would be less bothered about the garment aesthetics than the younger personas, as she would prefer it hidden, perhaps even accepting bulkiness if it equated to extra safety. However, this is not expressed through Nancy's persona description and perhaps reflects a culturally engrained expectation of older people coming from the participants.

Finally, the participants returned to the youngest persona, Emma, a 42 year old occupational therapist whose health condition can affect her balance and mobility. Here it was noted that Emma's work provides her with a good awareness of the challenges that come from ageing. Her clinical

background was thought to give her a more practical and functional focus on hip protection compared to Wendy and Delores.

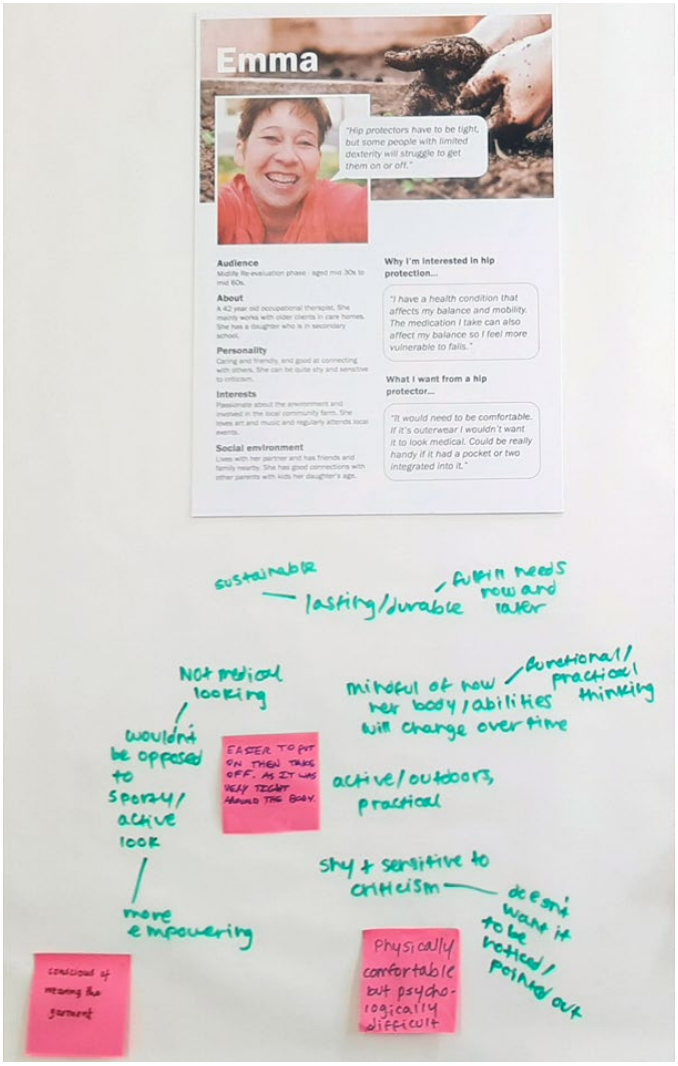


Figure 108: Evaluating the hip vest prototype through the persona of Emma.

The participants interpreted Emma's shyness and sensitivity to criticism as reasons why she would want a hip protector to be hidden. It was noted that because of her young age, she may feel more self-conscious about wearing the garment. In this scenario, the vest hidden under clothing could meet her expectations. Her preference for a non-medical looking garment was also raised with the view that the sporty aesthetic of the hip vest could be acceptable. The idea of activewear being empowering perhaps overcomes the self-consciousness and need to hide it.

By considering the hip vest in the context of the five personas, some key observations were established that can inform the ongoing development of the design concept:

- Different visual styles will appeal to different types of users. It's important to consider a range of styles relating to context and scenario of use.
- Garments worn on a regular day-to-day basis, and garments worn only when taking part in slightly higher-risk scenarios (such as exercising), are both applicable.
- Garments should be designed to be easier to use for people with low strength, dexterity, or mobility.
- Pad stability is important and it's vital that if the pads move against the body, there is enough tolerance in their positioning to still be effective in the event of a fall.

5.4.3 Hipwear design proposals

Through the principles of Action Research, the findings from the mechanical impact testing and the product user evaluation have informed the final stages of design development. The LHP005 hip pad prototype, introduced in section 5.4.1.3, had evolved from earlier experimentation with 3D printing flexible lattice structures, reinforced by an understanding of its impact energy absorbing capability. The development of LHP005 and further challenges that need to be addressed are discussed below.

The product user evaluation provided key insights into the wearability of the hip vest prototype. This review, coupled with critical reflection through the five personas, reinforced some established design criteria but also expanded further areas to be considered. In particular, ways to make the garment more accessible to people with reduced mobility, and how to further improve the stability of the hip pad location. By considering the needs and potential expectations of a range of different users, the hip vest format is explored through a variety of Hipwear design outcomes.

5.4.3.1 Hip pad design

The LHP005 prototype represents the most refined version of the hip pad developed through the practice-based research. The earlier iterations have led to an outcome that is shown to reduce impact energy below the hip fracture threshold at a moderate fall speed of 3.4 m/s. Crucially, this has been achieved in a pad only 9mm thick with tapered edges to help blend its visible outline into the shape of the wearer's hip (see Figure 109).

Figure 109: Hip vest produced by DM Orthotics fitted with LHP005 prototype pads.

Making the pads less bulky, so they don't affect the wearer's appearance, responds to one of the most significant barriers to acceptance of hip protectors. Unlike LHP004, the top surface of LHP005 was skinned to provide a smoother outer finish to make the pad less visible under the surface of the vest.

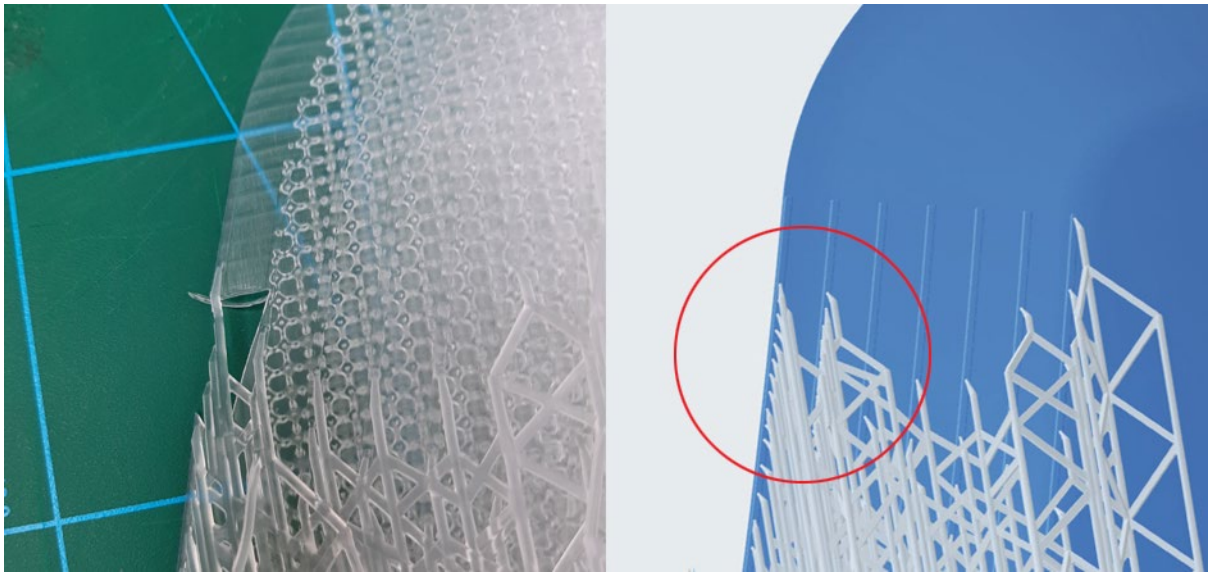


Figure 110: Left: LHP005 prototype with failed surface build area. Right: Increased support material applied in PreForm software to overcome the problem.

The pad edge thickness of 0.6mm presented some challenges to the build process on the Formlabs Form 3 machine. On the first build, a small area on the left hand edge failed, creating a gap in the surface. This was remedied by simply adding more support material to the affected area. Support material location points were applied manually in the PreForm software and spaced nominally 5mm to 10mm apart on the embossed ribs across the surface of the pad. Where the build fail occurred, extra supports were added, spaced around 2mm to 3mm apart (see Figure 110). For LHP005, the embossed ribs were detailed as straight lines that spread radially from the bottom curved edge of the pad. This was to help control the lateral spacing of the support material location points.

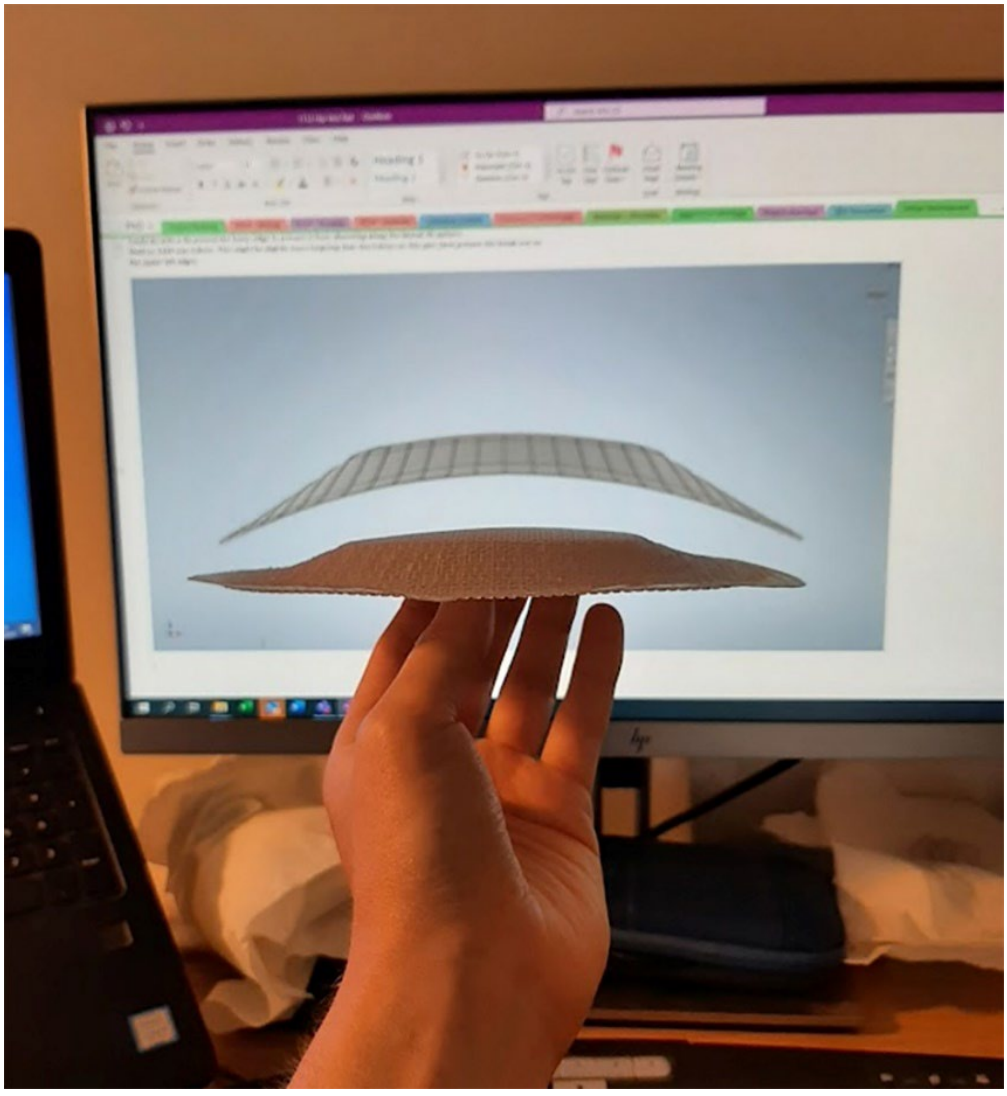


Figure 111: Illustrating the deviation between the LHP005 3D printed and 3D CAD profiles.

The extra amount of resin used, and any increase in build time between the two versions, was not recorded, although this is expected to be marginal. The re-printed version took 11 hours 19 minutes

to build and used 70ml of resin. This is a considerable improvement on the 15 hours 30 minutes build time for LHP004 and the 97ml of resin it consumed. However, in addition to the higher levels of impact attenuation achievable with LHP004, the overall structure of the pad helped to keep its shape consistent with the 3D CAD model. The tapering and very thin edge of the LHP005 pad, however, makes it much harder to control the shape. This is illustrated in Figure 111 where the curved profile seen in the 3D CAD is not reflected in the comparatively flat 3D print. This further reinforces the decision not to pursue 3D body scanning to capture the users hip geometry to directly inform the pad shape, as the 3D printed part would deviate from this. There is, however, enough flexibility in the LHP005 pad for it to easily curve around the hip when it is pressed in place by the vest garment.

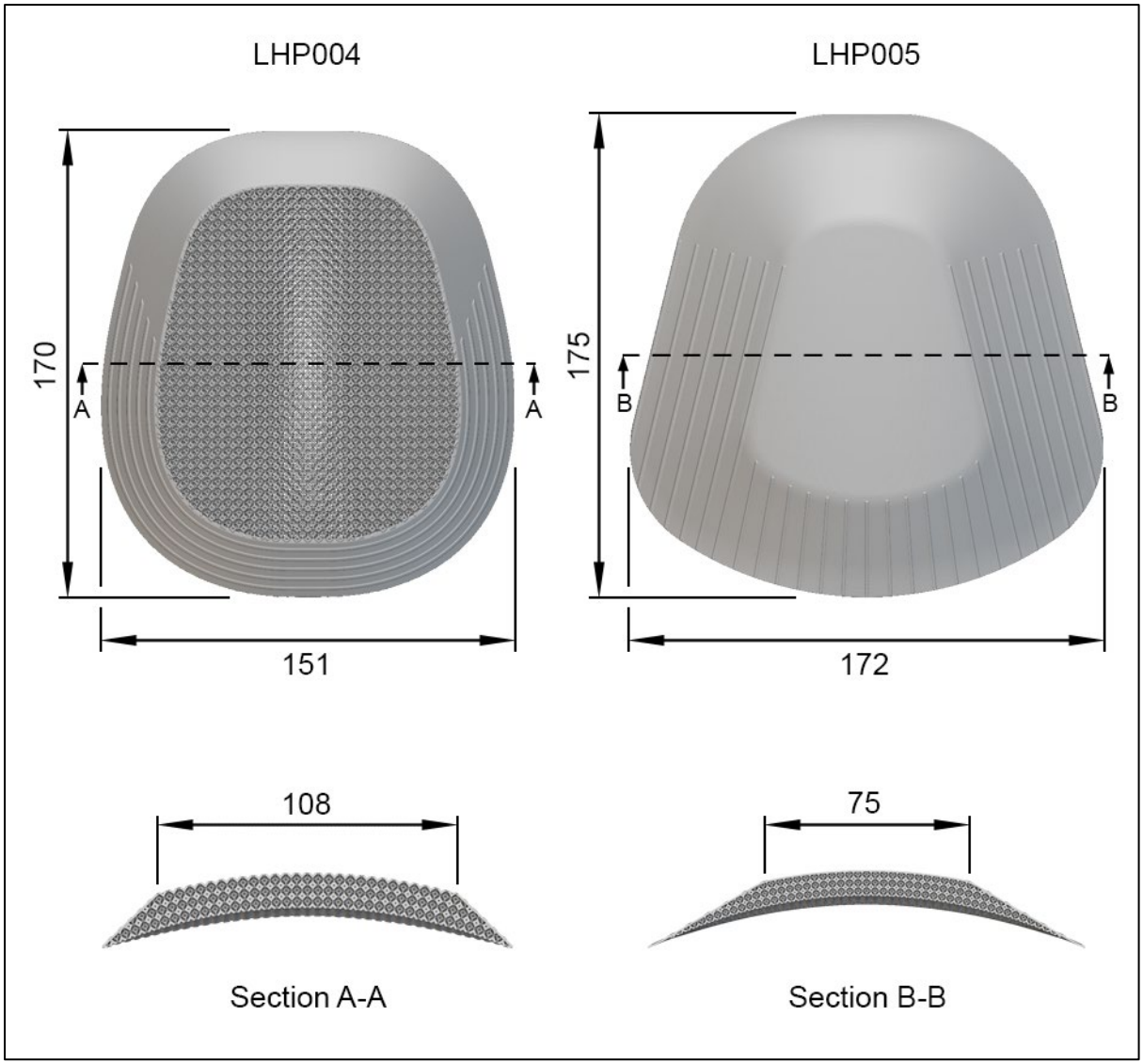


Figure 112: A comparison of the LHP004 and LHP005 hip pad prototypes (all dimensions in mm).

The final consideration for the LHP005 prototype is its size. By tapering the edges, the area of the pad with sufficient thickness (three layers of cells, 9mm thick) is limited to the central region. Although LHP005 complies with the recommended vertical length of over 160mm and minimum width of 120mm (Minns et al. 2007), the profile shape will affect its impact absorbing capability around the outer edges. Comparing the LHP004 and LHP005 designs (see Figure 112), the overall width and height of LHP005 was increased to help compensate for this. However, the section views demonstrate that across the central width of the pad, LHP005 has over 30mm less full protective thickness compared to LHP004. This means there is much less forgiveness in the positioning of LHP005 in relation to the greater trochanter in the likely event of the pad moving. Although the full thickness of the pad increases below the centre line (section B-B), providing more lateral tolerance, responding to the product user evaluation that if the pads move longitudinally, they will move upwards.

The limitation on pad size is dictated by the maximum build sizes possible using the Formlabs Form 3 SLA printer, wash tank and UV curing tank. The LHP005 was designed to the largest size possible to be accommodated by this equipment (see Figure 113).

Figure 113: LHP005 on the Formlabs Form 3 build plate after printing (left); transferred to the wash tank to remove the excess resin (centre); removed from the build plate and curing in the UV cure tank.

Formlabs manufacture a larger SLA 3D printing machine called the Form 3L. This has a maximum build volume of W335mm x D200mm x H300mm. Using this machine would allow for larger pads to be produced to extend the coverage achievable over the hip area. Further development could explore the potential of the 3D printed lattice geometry applied in a wider format as seen in the early

iterations of the hip vest (see 5.3.1.3). However, to allow for prototyping alongside the garment development, the current iteration of the hip pad (LHP005) has been used where its profile aligns with the shape of the vest side panel. The evolution of the vest concept, towards the Hipwear design proposals, is discussed below.

5.4.3.2 Hipwear refinement

The first hip vest prototype, produced by DM Orthotics, was developed to align with the early experiments with 3D printed lattice hip pads (see 5.3.3). This concept shifted the notion of the pads being laminated into the fabric of the garment (see 5.3.1.2) to a vest where the hip pads can be removed. Removable pads are proposed in the final design stage for three key reasons, reflecting design criteria discussed earlier (see 4.5):

- Laundry – with the pads removed, they cannot be damaged by the washing machine which could affect their ability to absorb impact energy.
- Product cost – removable pads allow users to buy several Hipwear garments whilst only needing one set of hip pads that can be used in any of them. The pads are likely to be the most expensive element to manufacture, so this will allow individual garments to be sold at a price that is comparable to equivalent vests. This will help facilitate daily use but will also allow a choice of different Hipwear styles depending on the context of use (discussed further below).
- Sustainability – the environmental impact of producing 3D printed hip pads at production volume is yet to be addressed. However, making the pads modular so they can be used with more than one garment reduces the overall number of pads needed to be produced. Removable pads also assist the garment end of life recycling strategy where they can be easily separated from the vest fabric. These are key criteria when considering the requirements of the EU's ESPR framework (European Commission 2024).

The first hip vest prototype, made using a polyester and elastane blend four-way stretch fabric, accommodated the LHP002 and LHP004 pads. This fabric was specified for convenience as it is a standard material used across many DM Orthotics' garments. It was designed so the pads could be inserted from the outside whilst also revealing the interesting visual detail of the lattice

structure (see Figure 114). However, this approach is not viable with the slimmer LHP005 as there is no distinct shoulder on the pad for the elasticated opening on the garment to cling to.

Figure 114: First vest prototype produced by DM Orthotics, fitted with LHP004 prototype pads.

The second vest prototype, adopted for the product user evaluation (see 5.4.2), is broadly the same in construction, using a lighter polyester/elastane mesh fabric for comfort and breathability. However, the pads are located in a pocket behind the side panel of the garment, accessible on the inside of the vest when it is removed. They are designed so the flexible pads can be deformed to fit through the pocket opening then return to their natural shape once inside (see Figure 115). This prototype also adopted a silicon-backed fabric panel over the inside of the pocket providing a grippy texture to help keep the pads in place. This was used as proof of concept, but the silicon pattern and colour could be applied in other stylised ways that are sensitive to the overall garment design. However, the value of the silicon grip was questioned during the product user evaluation (see

5.4.2.2), noting an uncomfortable feeling against the skin. The ability to recycle fabric at the end of the garment's usable life is also compromised if a silicon surface is bonded to it. Further experimentation with this material – or, indeed, alternative grippy fabric surfaces – is needed to establish its viability.

Figure 115: Vest prototype showing pad pocket and silicon grip backing. Inset image with LHP005 pad located in pocket.

The vest prototypes produced by DM Orthotics provided a means of critically evaluating the garment performance. A proof of concept is established, both in terms of the hip vest and the 3D printed lattice hip pad. The fabrics and construction of the hip vest were led by DM Orthotics based on the standard materials and manufacturing processes used in their factory. Further exploration of the potential of different fibres, fabric and construction methods (see 2.3.2) were not available with the company due to budget constraints. The pandemic also impacted on earlier opportunities to experiment more with the garment design. This is an aspect of the research that could be returned to in future design development.

At the hip vest interview stage (see 5.3.2) the visual language of the garment was explored through CAD renders. This approach is returned to now as a way of visualising the design before committing to further physical prototypes. In particular, the emphasis on developing a simple, feminine, and understated garment is demonstrated across a range of contexts established through the earlier research.

5.4.3.3 Hipwear visualisation

Responding to the opportunity for a sporty and empowering garment, Hipwear is presented as a base layer vest that could be worn completely under clothing, or as a visible layer depending on the context of use. Key design details (see Figure 116) include wide shoulder straps and stretch fabric to provide a secure and supportive fit. The fabric stretch direction running horizontally across the front and back panels will help hold the pads over the hips and make it easier to pull on and take off (see 2.3.2 and Appendix D). The side panels will be cut with the stretch direction running vertically to help with pad stability and the pads from riding upwards (a later suggestion discussed with Tony Ka Yiu Wang at Bodywear Lab). In this iteration, the garment would be constructed with adhesive bonded seams as discussed when prototyping the hip T-shirt (see 5.3.1.2).

Considering the requirements of the EU's ESPR framework, a bio-based MMCF such as DuPont's Sorona Agile could be specified to improve the environmental performance of the garment. The part-plant-based renewable stretch material compares well with spandex (Lycra) when exposed to UV light, heat, and wear. It can also be dyed, is soft, breathable, and has permanent stretch and recovery properties, ideal for activewear (Dupont 2024).

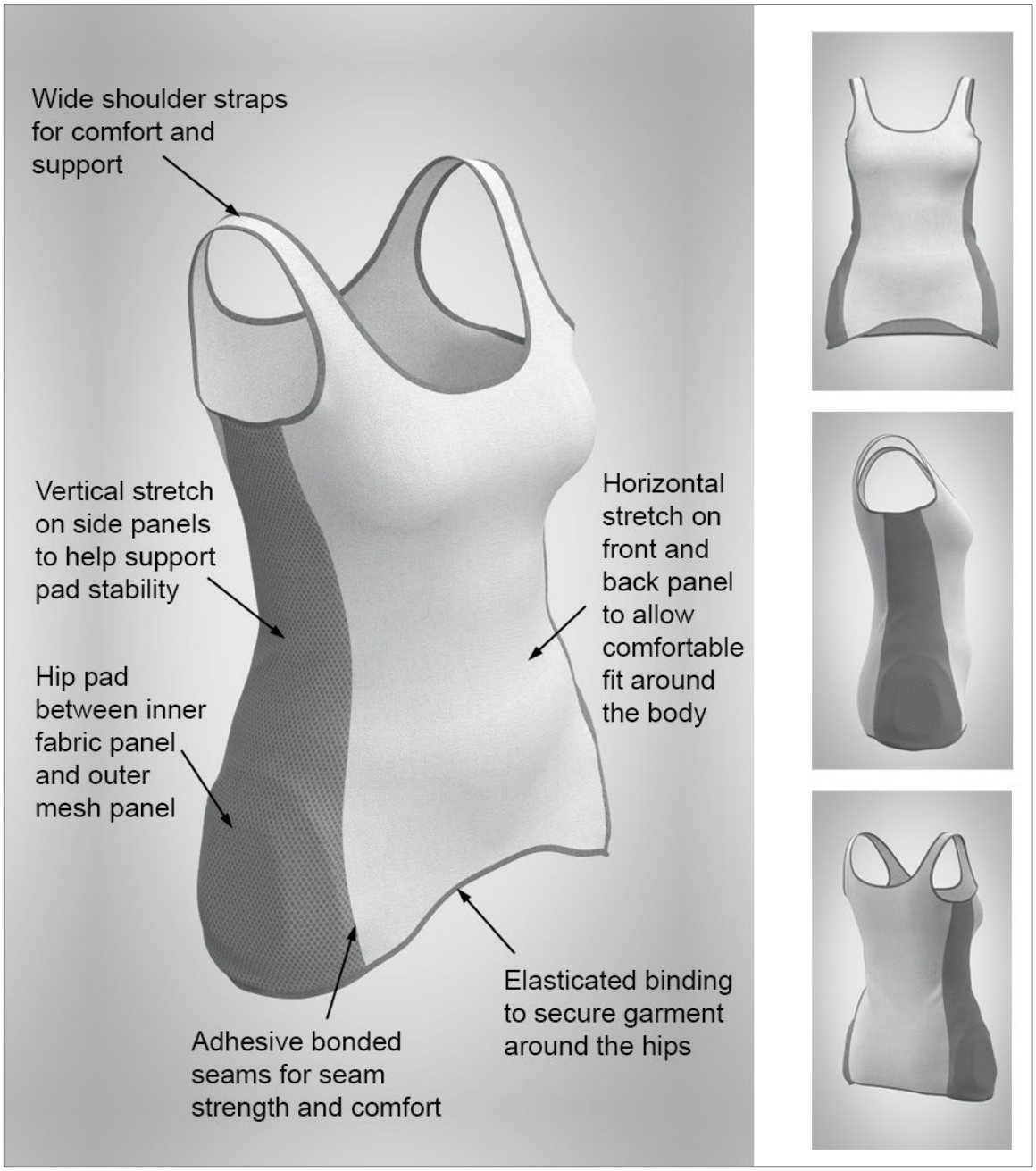


Figure 116: CAD renderings showing key design details of the Hipwear sports vest concept.

The binding around the lower hem of the garment is elasticated to help keep the back panel pulled down and stabilise the position of the hip pads. The fabric mesh on the outer side panels has a visual aesthetic commonly associated with sportswear, such as the mesh uppers used on the Addidas Futurecraft trainers (see Figure 21 in section 2.3.4). The translucency of this material allows the hip pad to be seen below the surface, revealing the technical sophistication of the 3D printed lattice. This detail reflects the visual language seen in performance sportswear, such as the Scott USA Airflex back protector (see Figure 13 in section 2.3.1), deliberately shifting the aesthetic away from medical

contexts. This effect is, however, difficult to replicate in the CAD renderings. It is also important to note that the outside edge of the pad is prominent as the CAD model is a 'rigid' shape that doesn't conform to the shape of the digital mannequin. The actual appearance of the pad under the fabric is less visible as demonstrated earlier in Figure 109.

The grey colour of the mesh is echoed in the edge bindings to establish a visual coherence across the garment. Of course, the colours, and even the mesh panel, could be specified differently. A simpler and more understated solution could be to use the same fabric across the garment (instead of the mesh on the outer side panels), and for it to all be white. This would provide the stretch compression and security of the sportswear vest but with a garment that can be worn discretely and not show through clothing worn above. Returning to the personas (see 5.4.2.3), this may suit someone like Greta who may wear the garment daily and want something simple but reassuring.

Figure 117: Hipwear casual vest colourways: white, khaki, coral, and charcoal.

The earlier consideration of a simple colour range for the sports vest concept (see 5.3.1.3) can be applied again to the updated design (see Figure 117). With the mesh panel replaced with the fabric used on the rest of the garment, this iteration embodies a more casual aesthetic. The removable hip pads allow the user to own a variety of different coloured vests but use the same set of pads with all of them. In the context of exercise and sportswear, the vest could conceivably be worn with the pads layered over clothing. For example, Figure 118 illustrates the Hipwear garment worn over exercise leggings, suitable for a scenario such as the exercise classes for older people run by iCareiMove. Adopting specialist or protective clothing aligns with cultural norms of taking part in exercise, so in this scenario, users may be more amenable to visible hip pads. This approach is also contingent on the pad stability which would require further evaluation in this context.

Figure 118: Hipwear sports vest worn over exercise leggings.

In response to the demand for sophisticated and elegant hip protection (as opposed to casual and sporty), identified through the online survey data (see 4.3.5), the vest format can be easily adapted in terms of style, fabric, and colour. One approach to foster a simple, feminine, and understated aesthetic is to develop Hipwear as a camisole garment (see Figure 119). This could comprise of a close-fitting layer with narrower shoulder straps worn specifically as underwear. Reflecting on the

persona workshop (see 5.4.2.3) this style of vest resonates with the discussion about Wendy's preferences and the notion of 'prettier' looking garments.

Figure 119: Hipwear camisole concept

Finally, two alternative Hipwear design concepts were identified through the product user evaluation as areas for further development: leotard fastening and side opening. There is, however, a tension between these two approaches. Side opening could make dressing with the vest easier for people with mobility issues, but a leotard fastening could make the garment more difficult to put on and take off. These two options could be provided separately to expand the range of Hipwear garments available to suit different types of users.

Further work is warranted to explore the potential for more inclusive approaches to dressing with the garment, and adaptive fashion approaches championed by designers such as Ellen Fowles (Royal College of Art 2021) would be a good starting point. However, the current vest design already

demonstrates usability advantages compared to traditional underwear hip protectors. The garment can be stepped into and pulled up or pulled down over one's head to dress (and reversed to undress), offering some choice for the user for whichever way they find easiest. Not having to pull down the garment when using the toilet (as with underwear hip protectors) also improves the usability.

The option of a leotard fastening in the garment crotch could help to improve the stability of the pad position as reported during the product user evaluation (see 5.4.2.2). However, further research would be needed to investigate both the comfort and usability of this option. A similar effect could be achieved by wearing specially designed underwear with a grippy surface over the hip area (e.g., Velcro) that fixed to the vest where the pads are located. This would overcome the need for a fiddly fastening in the crotch and would probably be more appealing to male users where leotard garments do not typically align with cultural norms. Alternatively, to improve the tolerance of acceptable movement of the pads, where they are still able to effectively protect the greater trochanter, the pad width and height could be increased providing greater coverage. This would take advantage of the thin profile achieved with the flexible 3D printed lattice and revert to the early iterations of the hip vest (see 5.3.1.3).

5.4.4 Reflection

This section has covered the final stages of the practice-based design investigation. I have engaged with research *through* design to address the function, usability, and aesthetics of the hip vest concept with prototyping, testing and evaluation. The work has culminated in final design proposals for the Hipwear concept, reflecting the 'deliver' phase of the Design Council's Double Diamond. However, as is clear from the earlier discussion in this section, there is scope for further development of the concept and diversification of a range of Hipwear garments.

The mechanical impact testing demonstrated encouraging results for the 3D printed lattice hip pad at 9mm thickness. The LHP005 hip pad, following the 3x3x3mm Kelvin cell structure of the 1110 test piece, would be capable of preventing a hip fracture at a moderate fall speed of 3.4m/s. As discussed earlier, further testing is required to establish the impact attenuation at higher fall speeds, and what the implications of body heat and laundering might be for pad efficacy.

The print failure issue on the edge of the LHP005 hip pad was resolved by adding more support material in this area. However, Laser Sintering (SLS) or Multi-Jet Fusion (MJF) 3D printing would

negate the need for support material altogether. These technologies were explored earlier (see 5.2.1.3) but were perceived to have inferior tactile and visual qualities compared to the Stereolithography (SLA) resin parts. As the Hipwear design has evolved and the pad element has become less visible and enclosed in the fabric of the garment, it would be prudent to return to these other 3D printing methods to investigate the production of LHP005 and the impact attenuation properties of alternative flexible materials.

For the product user evaluation, the hip vest trial with participants, focus group to discuss their experience, and the workshop to reflect that experience through the eyes of the personas, was a successful methodology to illicit critical feedback on the design. It was also interesting to see themes raised by older participants in the hip vest feedback interviews (see 5.3.2), e.g., ease of getting on or off and pad stability, reflected through the evaluation process. This reinforcement of ideas across the separate research methods underpins the integrity of this qualitative research. Both approaches yielded broadly positive responses towards the hip vest concept. However, the main limitation to the hip vest trial was the use of substitute foam hip pads that did not precisely reflect the look and feel of the LHP005 design. Further product testing and evaluation is required using the actual proposed pad design, ideally with participants that more accurately reflect the intended audience. This would need research ethics approval, potentially as part of a clinical trial of the design.

The Hipwear design proposals have mainly focused on the sportswear concept. This theme has been prevalent throughout the research and has helped to shift the function, meaning and context of the hip protector garment towards a more empowering visual design language. The emphasis on a garment that implies mobility and exercise aligns with the active lifestyle required to support healthy ageing. CLO fashion software has been a powerful tool to help visualise these garments and understand their fit on the body. However, one drawback has been the inability to simulate the flexibility of the pads in the software. This has meant that the pads are displayed as a rigid part, fixed in space (i.e., they don't move with the avatar if the body pose is changed), with only the garment fabrics simulating their actual properties to move, hang, and stretch. This has also limited the potential of using the software's animation tools to simulate the garment as the wearer moves or changes position.

As discussed earlier, other iterations of Hipwear could include a camisole design, considering more sophisticated and elegant hip protection, identified through the online survey data (see 4.3.5). This also responds to the notion of the garment as underwear discussed in the hip vest feedback interviews (see 5.3.2). Approaches relating to more inclusive ways of getting into the garment and taking it off, and ideas to help stabilise the pad positioning have also been discussed. Overall, the

vest format lends itself to broader territory to diversify the design and appeal to a wider range of users. For example, the Hipwear sports vest could also incorporate a sports bra. Similarly, camisole garments can also include built-in cups to negate the need for a separate bra to be worn. Alternatively, the product could be developed into nightwear to provide protection for users if they need to get out of bed during the night. Finally, Hipwear could be developed in response to the growing 'shapewear' industry (worth $2.4 billion in 2022 (Straits Research 2024)), with compression garments designed, primarily for women, to create a more flattering body shape. All these areas could provide further motivation to engage with hip protection but are outside the scope of this investigation.

6 Conclusion

I have engaged with research *into* design, research *for* design, and research *through* design, to understand the opportunities to improve receptivity towards hip protectors and apply that understanding to the development of new protective clothing concepts. Innovation in hip protector design has challenged existing hip protector precedents across three key themes: function, meaning, and context. In the conclusion, I will critically reflect on my approach to the research and the outcomes developed through the design practice. I will also articulate the contributions to knowledge that have emerged through the project and discuss the opportunities for further research in this field that builds on the work presented in this thesis.

6.1 Critical discussion and reflection

The Design Council's double-diamond was a useful way of framing the methodological approach. The 'discover' and 'define' phases gave structure to the research *into* design and research *for* design, engaging the contextual review and the human-centred design research methods to understand the issues. This early activity reflects Findeli's (2016) notion of the role of the design researcher to identify the specific anthropological issue and engage the proper research enquiry. In the context of research *for* design, the insights from industry and clinicians, focus groups with active older people, and online survey, were drivers for innovation that directly informed the design criteria for new hip protector concepts. Although the reliability of this data could be improved by, for example, increasing the sample size for these methods, the triangulation of qualitative data demonstrated much consistency across the themes and design opportunities presented. As such, the criteria presented in section 4.5 provides a robust set of design constraints that have not only informed the development of hip protectors for this research project but would be helpful to other designers and manufacturers seeking to develop protective clothing, especially for older people.

Research *through* design was anchored in the 'develop' and 'deliver' phases of the project. Here the iterative development of design concepts through idea generation, material experimentation, and user feedback, have engaged with the principles of Action Research. I have built on my experience as a product designer to evolve concepts that respond to a social model of development (e.g., design concerned with improving the receptivity towards hip protectors) and medical model (e.g., design

concerned with developing energy absorbing materials to reduce hip fracture risk). Had my earlier training been in fashion design, then perhaps the practice would have been more invested in the specification and detailing of clothing concepts. Although my approach has placed the user at the centre of the design process, my practice has focused more on the meaning of the garment, rather than the making. The collaboration with DM Orthotics has therefore been an important part of the design research to realise garment concepts, although prototyping has been limited to only the fabrics, fibres and construction methods currently used in their factory. This has aligned with the hip pad development, a territory closer to product design, where my practice-based research has embraced a more hands-on and experimental approach. This dynamic illustrates the potential for further work through an interdisciplinary team of performance clothing and product designers.

As part of this critical reflection, it is helpful to return to the research question presented at the beginning of the thesis:

How can hip protector garments be designed to fulfil performance requirements whilst embodying a visual language that sensitively reflects the sociocultural and lifestyle aspirations of the people who would benefit the most from wearing them?

The question has prompted a rigorous research investigation, explored through the contextual review and design practice embracing inclusive design principles, to develop Hipwear design solutions. The conceptual framework, reflecting the theoretical foundation for this study, has provided a critical lens through which the practice-based design research has been evaluated. To re-cap, the three interrelated principles, implicit in the research question, are:

- Hip protector design informed by both medical *and* social models of development, reflecting physical and psychological needs of users.
- Hip protector design that explores the cultural negotiation of their meanings, recognising they are neither fixed nor absolute and are context dependent.
- Hip protector design as critical gerontology, challenging ageist attitudes and developing new products that empower healthy ageing.

I have used these explicitly as an evaluation tool in section 4.5 (establishing the design direction) and section 5.34 (reflecting on the refinement of design concepts). However, the principles have been a continuous means of reflection throughout the design research. The hierarchical structure of the conceptual framework suggests that the greater the depth of engagement with each principle, the greater the improvement in performance, visual language, and overall acceptance of hip protectors. With respect to these criteria, the success of the Hipwear design solutions is discussed below:

I have closely examined hip protector design precedents to understand how these can be developed or challenged, including new products that have emerged whilst this investigation has been underway that use fall detection and airbag technologies. This continued emphasis on technology-centred solutions that potentially overlook critical user needs (e.g., ease of use and aesthetics), demonstrates the need for a more holistic approach, informed by both medical and social models of development, of which I have adopted throughout this research project.

Although earlier investigations into energy absorbing surfaces, such as passive inflatable panels and 3D printed protective tiles, yielded some creative outcomes, the research into flexible 3D printed lattices demonstrated the viability of this technology as an impact energy absorbing material (notwithstanding the need for further testing discussed in section 5.4.1.3). In seeking to fulfil the performance requirements of a hip protector product, not only do most of the lattice test samples demonstrate better impact attenuation properties compared to two commercially available hip protectors (Fall Safe and HiP), but the lattice geometry adopted for the LHP005 prototype demonstrates comparable impact attenuation to the Fall Safe pad which is twice the thickness. Here, the physical needs of the user are met through improved comfort (due to a lighter, thinner pad) and protection from hip fractures, but the psychological needs are also addressed through a lower profile, less obvious and bulky hip pad. The demand for discreet hip pads is well established through the research, however, it is important that the feel of the pad and its thickness still evoke confidence that they will protect the user from injury. This is another psychological consideration that could be explored further, although erring towards a slightly thicker pad (than the Protex HiP product, for example) will also naturally offer greater protection.

Discomfort, difficulty of use, and loss of independence are reported barriers to using traditional hip protectors. By shifting away from underwear, Hipwear offers functional improvements in terms of ease of use when using the toilet, easier accommodation of incontinence products, and the benefits of a snug base layer through the vest design. The disadvantage of a base layer during warmer weather is obvious but the Hipwear format is versatile enough to be worn without layers on top, as illustrated with the Hipwear sports vest. This is also reflected in the simpler iteration, using a single colour, stretch Lycra and cotton blend fabric, to emphasise a casual appearance as opposed to active wear. The physical testing of garment prototypes with student participants yielded positive feedback overall in terms of comfort and ease of use. Testing with the target audience would be preferable, but the student feedback overcame the research ethics constraints of working with older people at risk of falls. Further testing and evaluation should be considered for future work, with a focus on the stability of the hip pads and the ease of putting on or taking off the garment.

By exploring the visual language of hip protectors, I have investigated how their meanings can be perceived more positively, shifting from 'garments of dependency' to 'garments of empowerment'. This approach has allowed me to consider how the meaning-making aspects of the design can reflect the sociocultural and lifestyle aspirations of potential users. The online survey respondents used terms such as 'medical', 'clinical', 'elderly', and 'old person', to describe the underwear hip protector example, assigning negative and ageist connotations. By moving away from underwear, the Hipwear concept removes the association between hip protection and specialist underwear, and the contexts of vulnerability and self-consciousness related to incontinence products.

Key design cues for preferred styles of hip protectors, such as 'simple', 'feminine', and 'understated', also generated through the online survey, provided a useful guide for the design direction for new concepts. The vest format presented through Hipwear is conducive to many different visual approaches to reflect the diverse needs and desires of users. Indeed, the Hipwear sports vest and camisole presented earlier are two interpretations of a simple, feminine, and understated approach, exploring both casual and sporty contexts, and a more sophisticated and elegant style. The focus of this investigation has been on the needs of women, which have been overlooked in the design of many existing hip protectors, but a vest garment can also be designed for men or gender-neutral in visual style.

Through the later stages of the design practice, I placed most emphasis on hip protection as activewear with a sporty visual aesthetic. This theme emerged consistently through the expert interviews, the online survey, and feedback from the participants of the iCareiMove exercise and balance classes. The response towards the appearance of the Hipwear concepts during the telephone interviews was also very positive, with participants expressing a clear preference to the design compared to traditional hip protector garments. The visual appearance of activewear evokes a sense of empowerment through its semiotic relationship with fitness and exercise. This expression of movement and energy, counter to 'medical' or 'clinical' aesthetics, could even be motivating for, as Fanny Karst puts it, "ladies who don't exercise" (see 4.1.3) but are keen to express the association, reflecting an inclusive design approach.

By expanding the contexts where hip protection might be worn, the research engaged with critical gerontology as an approach to not only understand the social construction of ageing relating to falls, hip fractures, prevention, and protection, but attempt to change it for the better. Hip protectors as activewear encourage users to take part in physical activity. The fear of falling and injury can cause people to be less active, compounding their fall risk by losing muscle strength and bone density. As exercise is the most effective way of preventing falls in older people (Bruce et al. 2021), it follows

that protective exercise wear could provide a powerful means of reassurance and motivation for the user.

The Covid-19 global pandemic disrupted plans to engage with local care homes and the opportunity to gather insights from the oldest hip protector users, and arguably those at the higher risk of falls and hip fractures. Ultimately, however, the shift in emphasis towards active-agers and younger audiences (e.g., those living with osteoporosis) was helpful to focus the research and move away from 'age' as a determinant for wearing hip protectors, instead focusing on 'fall risk', regardless of age. This felt particularly relevant when engaging Cohen's (2006) 'Four Phases of Adult Development', viewing old age as an holistic part of adult life, to represent the personas informed by the online survey responses.

The research question asks who would benefit the most from wearing hip protection. The breadth of feedback in the online survey from women in their sixties, and younger, living with osteoporosis, demonstrates the case for hip protection to be considered earlier in life. The priority for better design solutions for women was also reinforced by the survey sample being significantly female biased. Although the personas were not used to systematically evaluate design concepts (except during the later Persona Workshop), they emerged alongside the analysis of the online survey results helping to personify the data. This qualitative interpretation led to 'human centred' outcomes providing a more meaningful presentation of the data than tables and charts alone.

The final part of this reflection considers the implications for this research beyond the context of hip protection for people at risk of falls. There is a clear opportunity for the work to inform other forms of protective clothing, sportswear, and impact energy absorbing applications. The conceptual framework has demonstrated its value to manifest underexplored approaches to the design of hip protection. The opportunities to apply the same framework to the broader context of design that is inclusive of older people also begins to emerge. This reflects the project-grounded research approach in producing knowledge that is also generalisable enough to be useful to wider design practice (Findeli 2016). The context of the conceptual framework could therefore be expanded to embrace an anti-ageist, inclusive approach to design, that views ageing as a holistic part of adult life:

- **Design** informed by both medical *and* social models of development, reflecting physical and psychological needs of users.
- **Design** that explores the cultural negotiation of its meanings, recognising they are neither fixed nor absolute and are context dependent.

- **Design** as critical gerontology, challenging ageist attitudes and developing new products that empower healthy ageing.

This framework could be applied to a wide range of design contexts including, for example, products for mobility, furniture, or use in bathrooms or kitchens. Indeed, recent research by Age of Majority, a US company specialising in marketing to older consumers, reinforces the desire of older people to be independent and live as autonomously as they can (Taylor 2023). They describe an ageing gap as the "unmet needs that exist between current product and service offerings and the (currently ignored) functional and emotional needs of older adults" (Age of Majority 2023). The framework, tested through this research project, would be a meaningful tool to challenge the function, meaning and context of current products, to drive innovation and leverage better design solutions.

6.2 Contributions to knowledge

The practice-based design research has led to contributions to knowledge in three key areas:

1. Methodologies and artefacts relating to the technical development of a novel impact absorbing surface that can be integrated into garments.

The practice-based research *through* design has led to the development of a flexible 3D printed lattice hip pad. The prototype hip pad demonstrates impact attenuation properties comparable to a commercially available pad but at half the thickness (see 5.4.1). This represents a significant contribution to research in the field of protective clothing. Although research into impact absorbing 3D printed lattices continues to grow, this is the first mono-material, flexible and soft, protective hip pad designed this way.

2. A conceptual framework providing a lens through which the practice-based design research can be evaluated that could be generalised across the design of products for healthy ageing.

The conceptual framework (see 2.4) underpins a new approach to designing hip protector garments to improve their performance, visual language, and overall acceptance, for people at risk of falls and fragility fractures. The pinnacle of the framework emphasises hip protector design as critical gerontology, contrasting current approaches to technology-centred hip protection that prioritise a biomechanical approach. The value of the conceptual framework has been demonstrated through this research project and the Hipwear design solutions that have emerged. A new archetype for protective clothing has been developed, with the integration of hip protection into the lower half of

a vest garment. This is a promising outcome for the broader applicability of the framework across the design of products that support healthy ageing.

3. Design criteria, currently overlooked in existing hip protector garments, informed by an inclusive design approach that establishes a new visual language for these products.

The research conducted through the 'discover' and 'define' phases yielded a broad range of design criteria (see 4.5) that current hip protector garments do not fulfil. These criteria underpin Hipwear design innovation offering a new visual language for hip protector garments that shifts the perception away from medical orthoses to a lifestyle product. This is innovation that transitions from garments of dependency to garments of empowerment. The design criteria continue to inform further work in relation to post-doctoral or funded research projects. Indeed, the criteria could also be adopted by other designers and manufacturers seeking to develop protective clothing, especially for older people.

6.3 Suggestions for further work

This research provides a solid foundation for further work in the field of protective clothing and other applications for impact absorbing surfaces. The potential to take the hip pad development more broadly into protective sportswear clothing, such as ski sports or cycling, reflects the range of applications discussed in the contextual review (see 2.3.1). Clothing to protect other parts of the body to reduce fracture risk is an obvious progression of the research. The opportunities for smart materials applied to clothing to monitor the wearer's vital signs could also be considered (see 2.3.1). In the case of older people, the technology could also monitor anomalies in movement and predict fall risk.

Although body shape and sizing for Hipwear has been discussed, more work could be done to explore how the garment could be adjustable for a better fit or to accommodate changes in body shape. This could include the development of avatars generated from 3D body scans of potential Hipwear users to inform pattern designs in CLO software to accommodate specific body shape and sizes. This may also relate to more inclusive approaches to dressing with the garment to support people with less mobility. The need to readjust the hip pads after movement was also noted in the earlier evaluation, with suggestions for approaches such as leotard fastenings (see 5.4.2.2). Further testing and evaluation could examine the stability of the hip pads and the ease of putting on or taking off the garment. Working with specialists in performance garment design, further investigation

into garment construction, including seamless knitting technology and prototyping alternative fibre and fabric combinations, is also warranted.

The design requirements have focused on the needs of women who are particularly underserved by current hip protector garments. Indeed, other avenues for further investigation, such as an integrated sports bra or body conforming shapewear have also been suggested (see 5.4.4). Although the Hipwear concept provides flexibility towards gendered styling, this research has had limited input from men, suggesting further research, involving male participants, could explore the “unmet need” (Sing et al. 2023) to prevent hip fractures in men.

As discussed earlier, further work is needed to investigate the long-term effectiveness of the 3D printed lattice hip pad, such as impact testing at higher speeds, at different temperatures, and after repeated impacts or wear (see 5.4.1.3). The opportunity for self-adhesive 3D printed pads, that bond directly to the wearer’s skin, following the work of Minns (2008) and Post et al. (2019), could also be explored. This would negate the need for the garment whilst still offering low profile and discreet protection.

The use of 3D printing to manufacture protective pads at scale presents challenges in terms of environmental sustainability. For example, the high energy consumption of 3D printing machines, the petrochemical basis of 3D printing resins, and dangerous volatile organic compounds (VOC) emitted during the process (All3DP 2023). With Hipwear, the protective pads can be used with more than one garment, reducing the overall number of pads needed to be produced. The removable pads also assist the garment end of life recycling strategy where they can be easily separated from the vest fabric. However, more could be done to improve the overall sustainability of the product. At the University for the Creative Arts, the Centre for Sustainable Design (CfSD) are conducting a study exploring the sustainability of cricket equipment (University for the Creative Arts 2022). New designs for hip protector garments could, for example, follow the approaches taken to develop circular cricket batting pads (Sanchez-Moreno and Charter 2023), although their ‘hard shell’ kneecap protector still uses 3D printing, albeit with a recycled filament. It would also be worth exploring BioCirflex flexible 3D printing resin, developed by Balena, recently used by Vivobarefoot to create a 3D printed compostable shoe (Dezeen 2024). End of life solutions for the Formlabs Flexible 80A resin are limited (ultimately, it would go to landfill or be incineration), so a compostable hip pad could be a more sustainable alternative. These ideas present further opportunities to explore a more progressive business model for selling hip protection, such as a subscription service, to maintain control of material flows and engage with the circular economy (Ellen MacArthur Foundation 2018).

Similarly, broader requirements for the sustainability and circularity of hip protector garments should align with the European Union's ESPR framework.

Finally, further work could build on the conceptual framework and explore how the three principles can be more broadly applied to product design that supports healthy ageing. Across many markets targeted at older people, products fail to meet the lifestyle aspirations and goals of their intended audience. Traditional narratives of ageing remain a pervasive force, widening the gap between what older adults theoretically need and their actual demands as users (Coughlin 2017). Challenging the function, meaning, and context of products designed for older users, whilst reframing aging as part of the natural life-course, is a vital opportunity for interdisciplinary design teams.

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8 Appendices

8.1 Appendix A - Human-centred design research during the pandemic: using an online survey to inform personas of women at risk of hip fracture

Simon Richard Andrews (2023) Human-centred design research during the pandemic: using an online survey to inform personas of women at risk of hip fracture, Design for Health, 7:1, 120-132, DOI: 10.1080/24735132.2023.2186643

DESIGN FOR HEALTH
2023, VOL. 7, NO. 1, 120–132
https://doi.org/10.1080/24735132.2023.2186643

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Human-centred design research during the pandemic: using an online survey to inform personas of women at risk of hip fracture

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ABSTRACT

During the global pandemic, social distancing rules made it difficult to conduct human-centred research into hip fracture protection, and in-person focus groups were abandoned. An online survey was developed to safely gather insights from people living with osteoporosis who are at risk of fragility fractures. The survey data informed the design of five personas that provide a critical lens to drive innovation in hip protector garment design and evaluate ongoing concept development. Although the pandemic disrupted people-facing research, the use of survey data provided a greater breadth of voices to inform the personas than focus groups alone.

ARTICLE HISTORY
Received 22 December 2022
Accepted 28 February 2023

KEYWORDS
Hip protector; survey; persona; Covid-19

Introduction

The practice-based PhD project, 'Innovation in hip protector design: challenging function, meaning and context', was in its early stages when the Covid-19 global pandemic began. In the context of researching older people at risk of falls, there were significant moral and ethical challenges connecting to an audience who were particularly vulnerable to the virus. This paper discusses how design-led research was adapted in response to the extreme situation caused by the pandemic, and how human-centred design research could continue without direct access to people at risk of falls.

In March 2020, when the first UK lockdown occurred, the research was at a critical stage of recruiting participants to take part in focus groups. These would involve older participants discussing hip protectors face-to-face and handling physical samples and prototypes. Around 20 participants from community and care home environments were to be recruited. The constraints enforced through social distancing rules made it impossible to continue the research this way.

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Initially, 'personas' were to be developed to help inform the design of new types of hip protectors. Personas are imaginary characters that represent different user archetypes based on real people who have engaged with the research (RCA 2011). The personas help to focus the design practice on the specific needs and desires of users and provide a useful tool to evaluate design concepts. It was intended that the data gathered through focus groups would also inform the design of the personas. This would have been done by drawing on the lifestyle, interests, and characteristics of focus group participants. Although three focus groups were conducted before the pandemic began, there was not enough data gathered to develop a meaningful range of personas.

The constraints presented by the national lockdowns made the development of personas an even more critical part of the research process as engaging with actual participants became more challenging. Access to care home residents was impossible, so the research pivoted to 'active-agers' and people generally more susceptible to fragility fractures. This led to a new avenue of investigation, understanding the opportunities for hip protection including younger audiences, paving the way to breakdown ageist stereotypes of hip protectors and the development of more inclusive products.

To gain further insight into attitudes towards existing hip protectors – accommodating social distancing rules – an online survey was conducted, targeting members of the Royal Osteoporosis Society (ROS). A rich qualitative and quantitative data set was generated from the 156 responses, and the findings also helped to inform the development of a series of personas. Currently, there is a broad discussion on data-based personas but there is a lack of research in the literature relating to designing later-life personas (Schäfer et al. 2019). The development of personas that focus on mid to older age helps to address this issue.

Although the pandemic forced a shift from face-to-face research activity to an online survey, the data generated provided a greater breadth of voices to inform the personas than could be achieved by focus groups alone.

Background context of the PhD

Hip fractures are a major cause of long-term disability and can lead to a rapid decrease in healthy life years, especially for older people. They are the most common reason for older people to need emergency anaesthesia and surgery and the most common cause of death following an accident (Royal College of Physicians 2018). Women are four times more likely to suffer a hip fracture than men due to higher instances of osteoporosis and longer life expectancy (Parker, Gillespie, and Gillespie 2006).

Hip protectors, consisting of underwear with integrated pads over the hip joint, can reduce the risk of fracture when worn consistently (Santesso, Carrasco-Labra, and Brignardello-Petersen 2014). However, long term adoption of these products is low due to aesthetics, discomfort, difficulty in use, and acceptance of fall risk (Sims-Gould et al. 2014). Although women are at higher risk, they are underrepresented in the design of current underwear hip protectors which are often aesthetically and functionally better suited to men (Sims-Gould et al. 2014; Doherty et al. 2004). The PhD research challenges the existing medical model for the design of hip protectors, typically perceived as 'assistive technology', and questions how human-centred design practice can inform new designs of hip protector garments that address these issues.

Impact of Covid-19 on planned focus groups

Across the world, as face-to-face interactions moved to online platforms such as Zoom and Microsoft Teams, it was a natural response for research with participants to follow suit. However, the purpose of the original focus groups was to engage with the materiality of product development, with opportunities for participants to handle samples and physical prototypes. The personas – considered an important but secondary outcome – would have reflected the demographics of focus group participants with fictionalized characters developed from lifestyles and interests identified through transcript analysis. There are precedents for running online human-centred design research (eg frog 2020; Goodpatch 2020) but the lack of ability for feedback on materials would have made these far less worthwhile. The idea of posting samples to participants in advance of an online focus group was considered, but the cost, and concerns about coronavirus surface contamination made this unfeasible. Access to prototyping facilities were also limited at this time, so these concerns were also coupled with uncertainty about having ongoing material development to share with participants. Fortunately, opportunities for this kind of research became viable again later as social distancing rules relaxed. However, at the time there was no way of knowing when that would happen. Developing an online survey was a rational way of maintaining primary research activity during this challenging period, although this felt like a compromise, making the best of a bad situation.

Survey and persona methodology

The online survey gathered 146 responses from women but only 9 responses from men, and 1 response from a non-binary man. The high proportion of female respondents reflects the higher instances of osteoporosis found in women. It may also simply indicate that women are more highly represented

within the ROS membership. They were an appropriate sample group for the research as people with osteoporosis, a disease that causes low bone mass and deterioration of bone tissue, are at higher risk of fragility fractures (NICE 2017).

The survey was anonymous, and respondents were notified at the start that by completing the survey they were providing consent for the information they provided to be used in the study. Ethical approval for this research was granted by the UAL Research Ethics Sub-Committee (RESC).

The survey was designed to examine whether the contexts of gender, age, history of hip fracture, and the respondents' own perceived risk of falls, have a bearing on the attitudes, and acceptance, of hip protectors. Two different types of hip protector were presented in the survey: the Fall Safe underwear hip protector and the HiP padded belt hip protector that can be worn over clothing. These were chosen to investigate the preferences of hip protectors hidden under clothing or worn visibly over clothing. The responses were systematically analysed using ATLAS.ti qualitative data analysis software (Scientific Software Development GmbH 2022) and coded according to statements that qualify as design criteria. Norman's (2005) three levels of design interaction – visceral, behavioural and reflective – provided a meaningful way of organizing the codes into distinct categories. The visceral level of a design is concerned with its visual appearance and our immediate response to it. The codes generated from comments about the visual appearance of the hip protectors were categorized into the 'visceral group'. The behavioural level relates to the effectiveness of use of a product, how well it fulfils its intended purpose. The codes relating to the perceived function or performance of the hip protectors were categorized into the 'behavioural group'. Finally, the reflective level is where the meanings of an object are placed in the context of the user; what does using or owning the object 'say' about the user? How does it reflect their self-image, status or invoke personal meaning? The codes related to comments about how the hip protector would make an individual look (especially to others) and feel were categorized into the 'reflective group'. This qualitative insight, and answers relating to context of use and style, revealed patterns that helped to inform preferences and characteristics to shape the personas.

It was important to create personas that represented users at different life stages. Older age is a risk factor for hip fractures but conditions such as osteoporosis can create risk for younger people too. Psychologists, such as Erikson (1963), have theorized the different stages of the life course, attempting to map psychosocial development from childhood to old age. More recently, Cohen (2006) has explored the psychology of old age within the

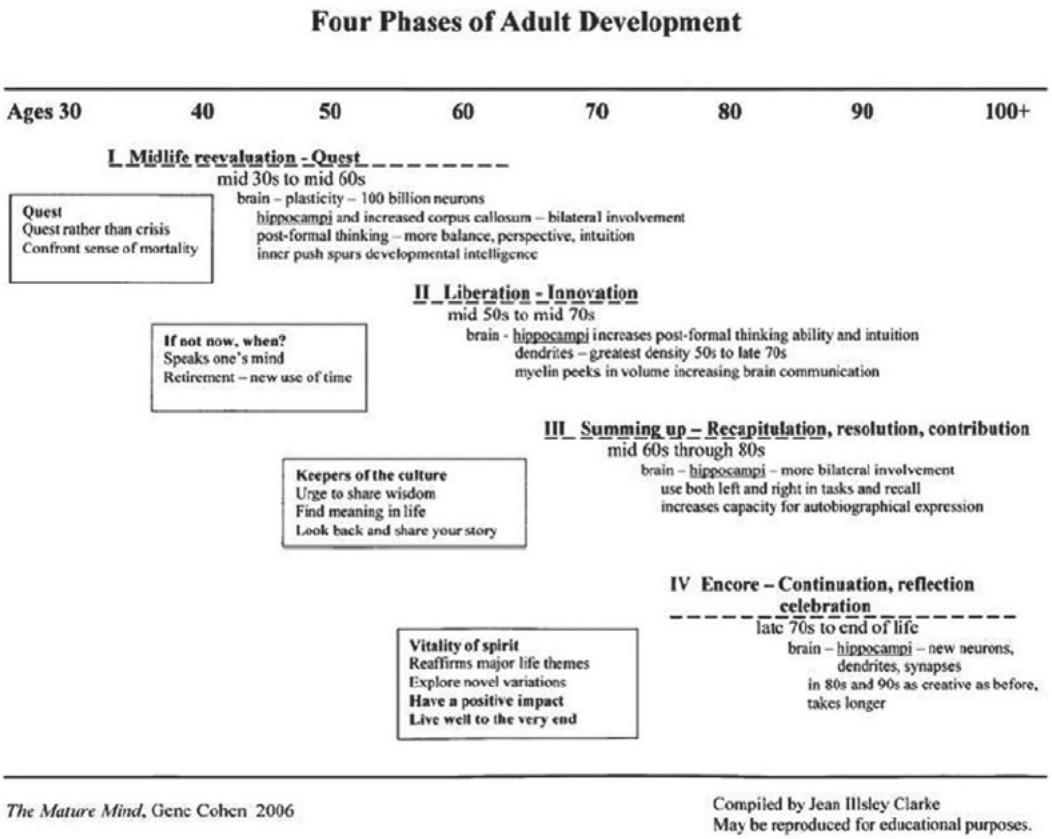


Figure 1. Cohen (2006). Four phases of adult development. Compiled by Illsley Clarke (2013).

wider context of adult development, and determined that age should not be a barrier to living creative and meaningful lives (see Figure 1).

His framework has four phases starting from a midlife revaluation, or 'quest', and builds to a final 'encore' phase, living well to the very end. The language used in this approach reflects positive attitudes towards ageing and views it as a holistic part of adult life. This is a useful tool when considering hip protector users, different contexts, and scenarios of use. For example, products designed for people living in the final phase may have different needs and desires compared to a person in the 'liberation' phase. Framing the personas this way, an opportunity to challenge ageist attitudes can be mediated through the development of new designs for hip protection, inclusive of younger and older people, that reflect positive messages about ageing.

Persona details such as personality, interests, and social environment, were also shaped by comments made in the survey and narratives identified through earlier focus groups and later telephone interviews. Images of women that represent the personas, and other contextual lifestyle images, were purchased or sourced royalty-free from stock photography websites and used within their licencing rules. Quotations were paraphrased, or taken directly from the survey responses, to shape the

personas' attitudes towards hip protectors. A persona template, developed by Nesta (2014), was adapted to accommodate three statements:

- How I feel about hip protectors
- Why I'm interested in hip protection
- What I want from a hip protector

Responses to these statements reflect the lifestyle and life stage of the five personas created to engage with Cohen's framework. It is this aspect of the personas' development that is presented below.

Personas informed by survey data

Older survey respondents tended to prefer hip protectors that were discreet and hidden from view. When asked what changes to the appearance of the underwear hip protector would make it more appealing, a higher proportion of women aged 70 and over provided responses in the visceral and reflective categories (see Figure 2). Similarly, 65% aged over 70 (n = 26) would prefer to wear a hip protector hidden under clothes, compared to 46% of women aged 59 and under (n = 18) (see Figure 3). Conversely, 56% of women aged 59 and under (n = 22) would wear a style of hip protector that was visible over their clothes if they liked its appearance, compared to only 33% aged over 70 (n = 13) (see Figure 4).

This translated into the persona development: For example, Greta, a 77 year old retired teacher (see Figure 5), has fractured her hip once before. She would value the peace of mind of a hip protector, especially when out with her grandchildren, but notes how important it is that you can't tell it is being worn, and that they're comfortable and effective.

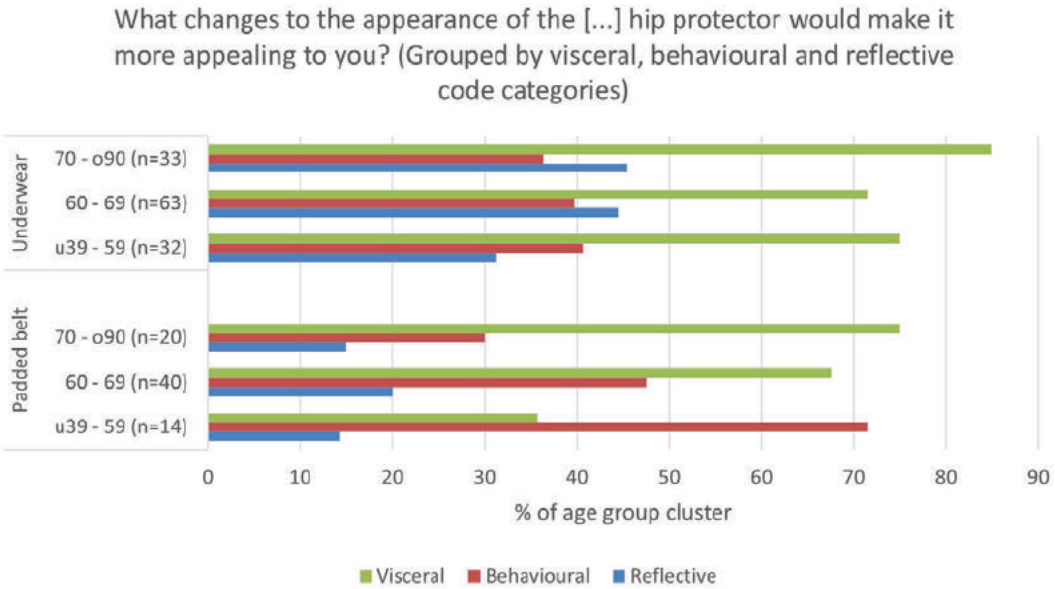


Figure 2. Comparing visceral, behavioural, and reflective categories of codes, clustered by age.

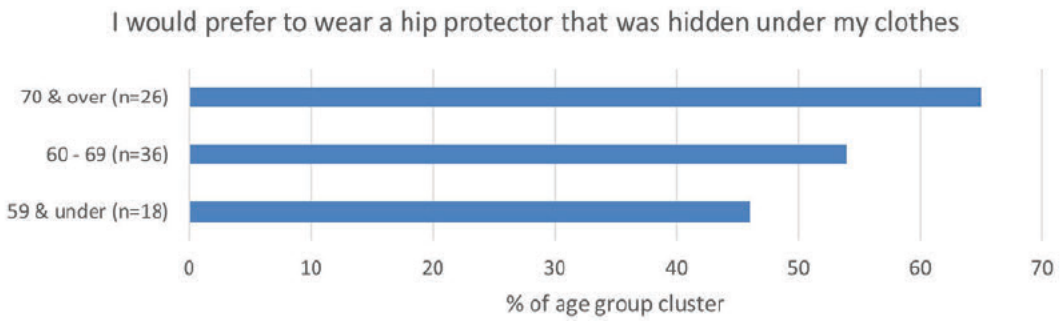


Figure 3. Preference for a hip protector hidden under clothes, clustered by age.

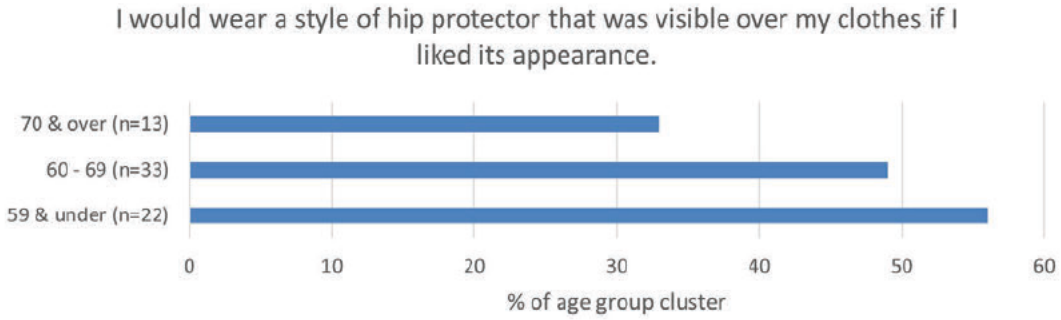


Figure 4. Responses to wearing a visible hip protector if its appearance is liked, clustered by age.

Nancy is in the 'Encore' life phase and has recently moved into an assisted living apartment. She is concerned that the minor falls she has experienced could become more serious. She would prefer to wear a hip protector hidden under clothing, but comments that they need to be much more slimline. Wendy is a younger woman who works full time, in the 'Liberation' life phase, and living with osteoporosis. She is style conscious and is more receptive to clothing with integrated hip protection designed in a chic way.

Younger respondents tended to reflect more on the function and performance of hip protectors. When asked what changes to the padded belt hip protector would make it more appealing, 71% of responses from women aged 59 and under (n = 14) were in the behavioural category, with only 30% of responses from women aged 70 and over (n = 20) in the same category (see Figure 2).

Emma, aged 42, is the youngest persona and in the 'Midlife Re-evaluation' phase. Although her health condition affects her balance and mobility, her role as an occupational therapist also gives her insight into the difficulties older people might face. For example, she observes that people with limited dexterity might struggle to get a hip protector on or off if it's too tight. Her involvement in the community farm underpins her suggestion for hip protectors worn over clothing to include integrated pockets.

Many of the respondents, even into older age, continue to lead very active lifestyles. For example, 38% of women aged 70 or over (n = 40) said they would wear a hip protector whilst exercising, and activities such as

Audience
Summing up phase - aged mid 60s through 80s.

About
A 77 year old retired teacher who lives with her husband. They rely on a fixed income and have to budget carefully.

Personality
A reliable and supportive person. She truly enjoys helping others but sometimes overcommits and is unwilling to ask for help herself.

Interests
Has a keen interest in the arts and enjoys theatre and music. She began painting and drawing in later life.

Social environment
Family is very important to her and she is a dedicated grandmother. She has one or two close friends but mostly spends time with her husband, children and grandchildren.

Why I'm interested in hip protection...

"I'm aware that age is a risk factor but I also have severe osteoporosis. Last year, I fell and fractured my hip."

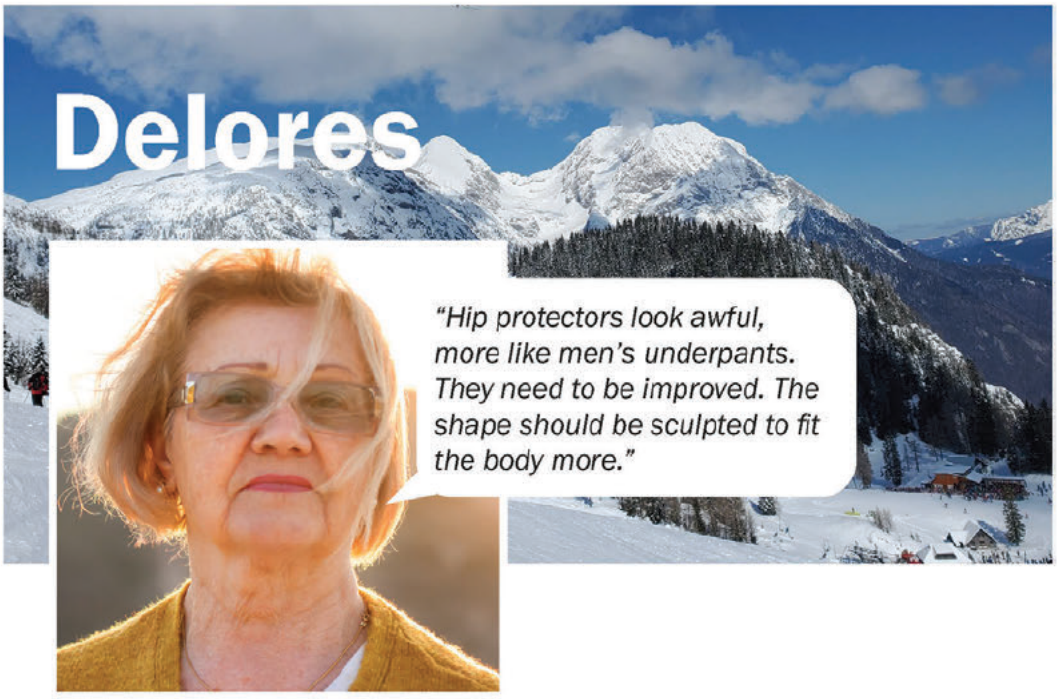
What I want from a hip protector...

"The most important thing is that you can't tell a hip protector is being worn, and that they are comfortable and effective. Some peace of mind when I'm out and about would be good."

Figure 5. Example of the persona 'Greta'.

walking (ie rambling or hiking), skiing and cycling were also reported. This is an opportunity for the personas to challenge ageist ideas about lifestyle and being "too old" to do certain activities.

Delores is 66 years old and is a keen skier (see Figure 6). She has always lived an active life and enjoys the outdoors and travelling. She is very critical of existing hip protector designs, noting that the shape should be better sculpted to fit the body. She suggests looking to padded cycling shorts as a potential hip protector solution that would not affect your exterior appearance.



Audience
Liberation phase - aged mid 50s to mid 70s.

About
A 66 year old, recently retired environmental consultant who lives alone. She is looking forward to spending more time relaxing and enjoying life.

Personality
Warmhearted and approachable, with an altruistic spirit and a friendly disposition. She can be a little unfocused and disorganised at times.

Interests
Has always lived an active life, loves being outdoors and travelling. She learnt to ski as a teenager which is a passion that has remained with her since.

Social environment
Recently separated and looking to forge new connections and friendships. She regularly meets for walks with a local ramblers group.

Why I'm interested in hip protection...

"I had an unexpected fall last year that has really affected my confidence. I was also recently diagnosed with osteopenia."

What I want from a hip protector...

"Cyclists wear padded shorts when sitting on a saddle. I was thinking that the hip protection might look something like that. Something that would not affect your exterior appearance and with a woman in mind - like a legging."

Figure 6. Example of the persona 'Delores'.

Discussion

The survey data has provided key insights to inform the development of personas at different life stages. When suggesting ways hip protectors could be improved, visceral and reflective responses appeared to become more likely with age, although the opposite was true for behavioural responses. A greater emphasis on the visual appearance of the garment, and how one

appears to other people, perhaps reflects internalized ageism and the highly negative ways older women have learnt to evaluate their bodies and appearance (Hurd Clarke 2010; Twigg 2013). The younger respondents were more greatly represented in the lower fall risk categories. One explanation for their bias towards behavioural responses could be that issues such as comfort and performance are seemingly more pressing for a group who are more likely to only wear hip protection when knowingly engaging in higher risk activities. These trends are reflected across the five personas developed.

Overall, this way of developing the personas has extended the breadth of exploration and interpretation of the survey data. By closely scrutinizing the qualitative data and reimagining the voices of the respondents through these fictional archetypes, the survey analysis has cultivated tangible 'human centred' outcomes that go further than presenting the findings through charts and graphs alone. The focus groups originally planned would have benefitted from feedback on physical samples and prototypes. However, the data to inform the personas would have been quite narrow with far fewer participants at later life stage only. The survey sample size and diversity of age allowed for meaningful development of personas at different life stages.

Putting people at the centre of the design process is vital for the inspiration and evaluation of new hip protector design concepts. When mapping the personas against these concepts, we can ask, for example, how might Greta or Nancy's needs differ from Emma's? We may also explore how the visual language of other types of protective clothing – particularly sportswear conveying action, adventure, or empowerment, often marketed towards younger users – could be appropriately diffused upwards towards older users at risk of falls.

Limitations

The online survey was an adaptation to practice-based research driven by social distancing rules. However, there are some limitations to the approach that were also symptomatic of the extreme circumstances faced during the pandemic. The need to adapt research methods quickly, coupled with the pressure of lockdown life experienced by the researcher, impacted on the time and 'thinking space' required for careful planning. For example, the survey questions were developed to explore attitudes towards hip protectors but the opportunity to create personas from the data was only realized later. Some more strategic planning of the survey questions, especially relating to personality and lifestyle, could have been included to help build the profiles more directly.

Using an online survey instead of in-person focus groups overcame social distancing rules and allowed a broader demographic to engage with the

research. However, the survey itself presents its own ethical challenges. Access to online surveys is not wholly inclusive as some of the target audience may be without internet access or lack digital literacy skills. In addition, whilst the target audience of ROS members provided insights from people living with osteoporosis, it is not representative of wider populations at risk of falls. Surveying other target groups and providing paper-based or in-person responses after lockdown restrictions ended, would help in both regards.

Men are also at risk of hip fracture but a very low response rate (n = 9) in the survey made it difficult to generate male personas. Similarly, the opportunity to explore non-gendered hip protection could be developed much further. Again, widening the target survey sample would help to develop this.

Conclusion

When the pandemic began, the shift away from focus groups to an online survey was a necessary response, but not without concern that the quality of research would be compromised. However, the adapted methods have helped to inform the development of a rich collection of personas, representing women at different life stages, and reflecting the trends identified through the analysis of the survey data. The success of the personas, in terms of the breadth of data that supports them and the inclusion of a wider age range, would not have been achieved without the adaptations to the research imposed by the pandemic.

Targeting members of the ROS provided meaningful feedback from a group particularly at risk of fragility fractures, including women represented through Cohen's four phases of adult development. This has led to an understanding of the opportunities for hip protection beyond only the very elderly, opening new avenues of investigation for the PhD.

The five personas created provide a critical lens to drive innovation in hip protector garment design and evaluate ongoing concept development. The voices represented through the personas challenge the visceral, behavioural, and reflective attributes of existing hip protectors. In doing so, they question: how do we shift the perception of hip protectors from garments of dependency to garments of empowerment?

The Covid-19 pandemic placed significant constraints on this practice-based PhD research. However, like any design constraint, it also presented an opportunity for creativity and problem solving. Future generations of PhD researchers can benefit from the innovative methods and practice compelled by the pandemic, and should be reassured that adapting their methods, due to any challenging circumstances, can bring positive and new insights to their work.

Acknowledgements

The author would like to thank all those who participated in the survey and the Royal Osteoporosis Society for their support in promoting the survey to their members.

Disclosure statement

A small administration fee was paid to the Royal Osteoporosis Society for them to promote the survey to their members on their website and through their social media channels.

Funding

The PhD was initiated by the 3D3 Centre for Doctoral training, funded by the Arts and Humanities Research Council and the National Productivity Investment Fund (award reference 1934922).

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8.2 Appendix B - Designing better hip protectors: a critical and contextual review examining their acceptance and adoption in older populations

Simon Richard Andrews (2019) Designing better hip protectors: a critical and contextual review examining their acceptance and adoption in older populations, The Design Journal, 22:sup1, 331-345, DOI: 10.1080/14606925.2019.1595423

EAD 2019

Running with Scissors, 13th EAD Conference University of Dundee, 10-12 April 2019

Designing better hip protectors: a critical and contextual review examining their acceptance and adoption in older populations

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Abstract: Hip fractures are a very serious condition in the elderly, greatly increasing morbidity and mortality. Hip protector garments, with integrated impact absorbing or deflecting pads, are known to help reduce hip fractures when worn by high-risk populations. However, uptake of these products is low. By investigating academic studies and sales and marketing literature, this paper provides a critical and contextual review of barriers to acceptance and adoption of hip protectors amongst older adults. This is part of a broader PhD investigation to establish how hip protection can be improved through human-centred design. Discomfort is the most reported barrier to acceptance although there are several more, including aesthetics and difficulty of use. Receptivity towards hip protectors is key to eventual compliance, and design criteria including aesthetics, convenience, comfort and cost should be as important as the level of impact protection to the hip joint.

Keywords: Hip Protector, Hip Fracture, Elderly, Garment Design, Human-Centred Design

1. Introduction

This research represents the early stages of a PhD project examining falls in the elderly, in particular investigating the opportunities for improved forms of hip protection design. The study will inform the development of prototypes to understand how hip protection can be designed to look, feel and operate, in a way that is sensitive to sociocultural and lifestyle aspirations of elderly people, whilst reducing the risk of hip fractures caused by falls. Human-centred design will directly engage with people who are potential users of the product to inform the design development. In addition to understanding pragmatic requirements, a design language will stem from this research that embraces the reflective meaning perceived by users towards hip protectors. A human-centred approach will shift the emphasis of design intent beyond the technology-centred design language of current products.

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In order to understand the opportunities for improving the design of hip protectors, this paper reports on a critical and contextual review focusing on the acceptance and adoption of current available products for elderly populations. The aim of this review is to establish appropriate themes for enquiry within a human-centred design research context. This secondary research, and later primary research, will define the design opportunity and inform a design brief for new product development.

2. Context

Hip fractures are a major cause of long-term disability and can lead to a rapid shortening of healthy life years for older people. The average age of a person who fractures their hip is 77 years, demonstrating it is not only the very old who are at risk (National Clinical Guideline Centre, 2011). More than 90% of hip fractures occur as a result of a fall (Norton, Campbell, Lee-Joe, & Robinson, 1997), primarily when a person lands on their side and the impact force against the floor causes a break near the femoral neck (the section between the top of the femur and the 'ball joint' of the hip). Sideways falls increase hip fracture risk by 5-fold when compared to forward or backwards falls (Hayes, Myers, Morris, & Gerhart, 1993). Crucially, however, this risk increases by 32-fold when direct impact to the greater trochanter (the bony protuberance at the top of the femur) occurs (Nevitt & Cummings, 1993).

Elderly residents in nursing homes, or similar long-term care facilities, are most at risk of fracturing a hip. Tideiksaar (1997) claims that up to 50% of residents in nursing homes experience a fall every year, and that over 40% experience more than one fall. About 4% of these populations experience hip fracture every year (Chandler, Zimmerman, Girman, & Martin, 2000; Lauritzen, 1997; Singh, Sun, & Anis, 2004), which is up to 10.5 times greater than community dwelling elderly populations (Butler, Norton, Lee-Joe, & Cheng, 1996; Norton, Campbell, Reid, & Butler, 1999). An explanation for this trend is the tendency for long-term care residents to suffer from more chronic illness and mobility difficulties than their counterparts still living in their own homes. Indeed, Boonen, Autier, Barette, and Vanderschueren (2004) show that 20% of elderly community dwellers who survive a hip fracture have to move to a care home because of the disability and functional impairment the fracture brings. Magaziner, Hawkes, Hebel, and Zimmerman (2000) show that among hip fracture survivors, over 80% reported needing assistance bathing or to climb five stairs at both 12 and 24 months post-fracture. Further to the chronic morbidity that can be caused by hip fractures, approximately 20% of people who experience a hip fracture die within one year of the injury occurring (Leibson, Tosteson, Gabriel, & Ransom, 2002).

Women are statistically four times more likely to suffer a hip fracture than men (Parker, Gillespie, & Gillespie, 2006) due to higher instances of osteoporosis and longer life expectancy. However, by 2050 it is expected that this trend will reverse and annual occurrences of hip fracture will be greater in men due to an overall increase in elderly population and changes in demographics (Bleibler, Konnopka, Benzinger, & Rapp, 2013). The annual cost of medical and social care for all the hip fracture cases in the UK amounts to about £2 billion (National Clinical Guideline Centre, 2011). In the US, where there are approximately 150,000 hip fractures per year, the estimated cost of care is between $10.3 billion and $15.2 billion (Burge, Dawson-Hughes, Solomon, & Wong, 2007; Gillespie, 2001). The total number of hip fractures worldwide is predicted to rise from 1.6 million to 6.2 million by 2050 if no action is taken to reduce this growing health crisis (Kannus, Niemi, Parkkari, & Palvanen, 1999).

Hip protectors are an effective way of reducing the risk of hip fracture (Lauritzen, Petersen, & Lund, 1993). There are at least 26 different hip protectors commercially available (Laing, Feldman, Jalili, & Tsai, 2011). The most common hip protector designs comprise of underwear containing integrated or removable pads that provide impact protection over the greater trochanter region of the hip joint. Two main types of protective pad are predominantly found: soft, foam shock-absorbing pads (see Figure 1), or rigid plastic shells that deflect energy on impact. Although some designs make small concessions to gendered styling, most of the underwear products are available, or marketed, as unisex.

Figure 1. Fall Safe hip protector underwear shown with left hand shock absorbing pad removed from internal pocket (author's own photo).

Numerous hip protector patents were registered in the mid-nineties as the market grew, however, little innovation and development of these designs has been seen since then. In a systematic review of studies examining acceptance and adherence to hip protectors, Korall et al. (2015) note that, "despite improvements in the design of hip protectors over the last decade, we observed that discomfort, unwanted side effects, and poor ergonomics (e.g. complexity of use) persist as substantial barriers to their continued use." The effectiveness of reducing hip fracture risk when wearing hip protectors is well reported, especially in long term care contexts. For example, Hubacher and Wettstein (2001) report that 50% of all hip fractures can be prevented if hip protectors are worn. They assert, "that the percentage of preventable hip fractures is not higher is not due to any shortcomings in the mechanical protective effect of hip protectors but to insufficient willingness to wear them on the part of fall-prone senior citizens". Many studies report that participants find hip

protectors uncomfortable or dislike the way they look, which can negatively impact on the clinical effectiveness of intervention studies using hip protectors due to lack of compliance and limited 'wearing time' (Kurrle, Cameron, Quine, & Cumming, 2004).

Hip protectors that use inflatable technologies are now emerging with at least four start-up companies bringing new products to market. An airbag system, deployed from a belt, negates the need for bulky padding on the hips, overcoming some of the problems reported with underwear products. The Wolk, for example, uses inertial sensors to detect falls happening and automatically deploys airbags over the hips (Wolk, 2018). However, the initial cost, and ongoing 'recharge' cost for these types of products presents a significantly higher financial outlay than traditional hip protectors. Cianferotti, Fossi, and Brandi (2015) note that these types of devices could significantly improve comfort, therefore increasing compliance. However, the authors make reference to the International Hip Protector Study Group (IHPSG) recommendation that economic analysis should be included in future clinical trials of hip protectors (Cameron, Robinovitch, Birge, & Kannus, 2010).

The seriousness of hip fractures and devastating impacts on the health and wellbeing of elderly people, demonstrates the need for more effective fall prevention and protection interventions. The shortcomings of current hip protector designs are well established and explored in detail later in this paper. Although new airbag designs seek to provide more comfortable and discreet hip protection, this high technology solution potentially overlooks other critical user needs, perhaps alienating some elderly people at risk from falls.

3. Methodology

The research methodologies adopted align with the early stages of the PhD project investigating human-centred design methods to develop more widely accepted hip protector products. The Design Council's double-diamond methodology (Design Council, 2015) provides an established structure to frame the overall PhD investigation within four phases: discover, define, develop and deliver (see Figure 2). This paper reflects on the desk-based research established through the 'discover' phase, identifying precedents to evaluate opportunities for improvement, guiding concept development and prototyping. New knowledge will exist in the junction between technological innovation, inclusive design, fashion theory and product semantics, proposing new solutions to reducing hip fractures in the elderly. The practice will test theory in these domains to develop human-centred design solutions in response to technology-centred hip protector precedents.

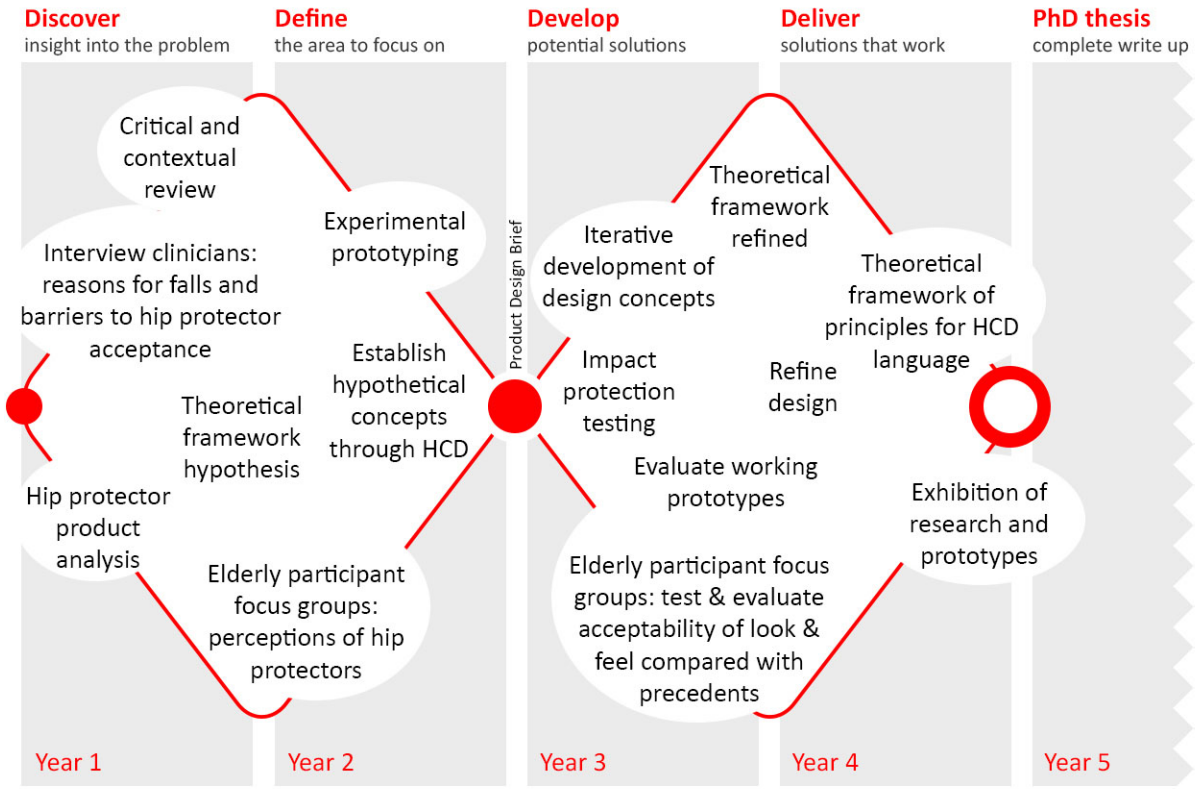

Figure 2. Summarised version of the PhD structure adopting the Design Council's double-diamond methodology. Adapted from Design Council (2015).

3.1 Review of studies into acceptance and compliance with hip protectors

An initial search of academic journal articles was conducted using a combination of terms, including "hip protection", "hip protector", "elderly", and "design", with no constraints on year of publication. The particular focus of the investigation was on studies where acceptance and compliance issues were examined. However, further reading relating to falls in the elderly and hip fracture prevention naturally occurred as part of the broader investigation. Two systematic reviews of literature were identified: van Schoor, Devillé, Bouter, and Lips (2002) and Korall et al. (2015). Their findings provided useful insights but also a means of cross-referencing articles already reviewed and highlighting other important studies not yet read. Barriers to acceptance and adherence were established across the review and the articles were categorised accordingly to establish the frequency of reported barriers. Several studies of care home populations report on system barriers, such as level of staff training and commitment to hip protector use (e.g. Burl, Centola, Bonner, & Burque, 2003; Cryer, Knox, Martin, Barlow, & Cantebury hip protector project team, 2002; Cryer, Knox, & Stevenson, 2006; Doherty, Glover, Davies, & Johnson, 2004; Forsén, Sandvig, Schuller, & Søgaard, 2004; Hubacher & Wettstein, 2001; Tavener-Smith & De Vet, 2006; Thompson, Jones, Dawson, & Thomas, 2005; van Schoor, Asma, Smit, & Bouter, 2003; Warnke, Meyer, Bender, & Mühlhauser, 2004). However, this paper only focuses on the barriers perceived by users associated with the design of hip protectors.

3.2 Analysis of hip protector market and garment design

The literature review was supported by a wider review of the market for hip protector products. Internet searches, adopting the same search terms as the literature review, provided a quick and

accessible way to establish key manufacturers, online retailers, and specific hip protector designs. The visual representation of products through sales images was of particular interest in relation to initial acceptance, and observations across a range of marketing material are reported on later. Further desk research into academic sources underpinned these observations.

3.3 Analysis of retail cost of hip protectors in relation to appearance and performance.

Further to the broader market review, a more systematic approach was also adopted. Laing et al. (2011) studied the effects of pad geometry and material properties on the biomechanical effectiveness of 26 commercially available hip protectors. The products they chose were representative of a range of different styles of hip protector garments. However, the study focused only on the force attenuation properties of the protective hip pad element, and did not analyse the respective garment. With reference to their study, the same 26 hip protector products were independently reviewed through the available online marketing material to correlate aesthetics and retail cost (two key factors influencing acceptance) with the biomechanical effectiveness reported by Laing and colleagues.

4. Findings

The most notable observation from this research is the positioning of hip protectors as a medical intervention as opposed to a consumer product. This finding reflects Pullin's (2009) recognition of the significant cultural differences found between product design and medical engineering. In this respect, the discourse concerning the design of hip protectors sits firmly within literature from the fields of medicine, nursing and gerontology. For example, Cianferotti et al. (2015) and Laing et al. (2011), assert that aesthetic considerations, are secondary to the biomechanical properties of hip protector design. Here the primary focus is on principles of engineering relating to shock-absorbing, or deflecting, materials that provide the optimum conditions to reduce the risk of hip fracture. Watkins and Dunne, (2015), whose expertise is in functional clothing design and broader classifications of protective garments, suggest a more intuitive approach:

> A garment cannot provide protection if it lies on a shelf. The designer's most difficult job is to design *acceptable* protective forms. The perfect protective garment would involve no trade-offs - it would meet an individual's physical *and* psychological needs. The ideal is often impossible to reach, so designers must work to maximise the degree to which each need can be met. (Watkins & Dunne, 2015, p. 254)

Within the published literature, no peer reviewed articles concerning the design of hip protectors were found in any journals related to product or garment design, or human centred design practice. Similarly, the market review suggests that existing hip protector products are generally marketed through organisations that specialise in mobility aids and assistive technologies, mostly targeting concerned relatives or institutions purchasing in volume. This presents a clear opportunity for the development of new insights into hip protector design and human centred research methodologies, and equally sets an agenda for better designed products aligned with lifestyle aspirations of older people.

4.1 Hip protector acceptance and compliance

Six key barriers to acceptance and compliance are identified by Sims-Gould, McKay, Feldman, Scott, and Robinovitch (2014) that are broadly reflected in the studies reviewed (see Table 1).

Table 1. Six key barriers to hip protector acceptance and compliance. Expanded from Sims-Gould et al. (2014).

Key Barriers	No. of studies identified where barrier is listed	Reference citations
Discomfort	18	Bentzen, Forsén, Becker, & Bergland, 2008a; Bentzen, Bergland, & Forsén, 2008b; Blalock et al., 2010; Burl et al., 2003; Cameron et al., 2011; Cryer et al., 2002; Doherty et al., 2004; Honkanen et al., 2006; Hubacher & Wettstein, 2001; Ledsham, Boote, Kirkland, & Davies, 2006; Milisen, Coussement, Boonen, & Geeraerts, 2011; Myers et al., 1995; O'Halloran et al., 2007; Patel et al., 2003; Sawka, Nixon, Giangregorio, & Thabane, 2007; Tavener-Smith & De Vet, 2006; Thompson et al., 2005; Woo, Sum, Yiu, & Ip, 2003
Dislike of appearance	9	Blalock, Demby, McCulloch, & Stevens, 2010; Cameron, Kurrle, Quine, & Sambrook, 2011; Chan, 2000; Forsén et al., 2004; Honkanen, Dehner, & Lachs, 2006; Hubacher & Wettstein, 2001; Myers, Michelson, Van Natta, Cox, & Jinnah, 1995; Patel, Ogunremi, & Chinappen, 2003; Thompson et al., 2005
Difficulty of use (getting on and off due to physical frailty)	9	Bentzen et al., 2008b; Chan, 2000; Doherty et al., 2004; Forsén et al., 2004; Ledsham et al., 2006; O'Halloran et al., 2007; Patel et al., 2003; Tavener-Smith & De Vet, 2006; Woo et al., 2003
Development of unwanted side effects such as heat rash	8	Bentzen et al., 2008a; Bentzen et al., 2008b; Blalock et al., 2010; Doherty et al., 2004; Forsén et al., 2004; Ledsham et al., 2006; Milisen et al., 2011; Tavener-Smith & De Vet, 2006
Loss of independence, especially related to using the toilet	4	Blalock et al., 2010; O'Halloran et al., 2007; Parkkari, Heikkilä, & Kannus, 1998; Tavener-Smith & De Vet, 2006
A lack of understanding and acceptance of fracture risk	4	Chan, 2000; Doherty et al., 2004; Milisen et al., 2011; Patel et al., 2003

These themes offer key points of enquiry for further empirical research, and provide useful criteria to inform a design brief for new product development. Across the studies reviewed, issues relating to discomfort, dislike of appearance and difficulty of use, appear to be the most commonly reported barriers to long-term acceptance.

Discomfort relates to hip protectors being generally uncomfortable to wear, with extreme discomfort and pain observed if the product causes unwanted side effects such as heat rash. Patel et al. (2003) found, of the 62% of women who refused to wear the protectors for their study, the highest proportion (34%) said that it was because they were uncomfortable. Tight fitting underwear - and the potential for outer garments to feel tighter as the protective pads increase the hip width - can feel more uncomfortable sitting down, than standing up (Blalock et al., 2010). Similarly, users could

be more aware of feeling the hip protectors when walking rather than at rest. Wearing hip protectors in bed might be uncomfortable, particularly if the user is trying to sleep on their side (Ledsham et al., 2006). When interviewing care home residents, Doherty et al. (2004) reported that comfort emerged as the most important consideration. They found that the hard shell protectors dug in and rubbed, causing discomfort. A resident described the hard shell as, “like a piece of plaster, a piece of a building […] it was hard and uncomfortable. It rubbed…”.

Dislike of appearance is two-fold: negative perceptions towards the overall look of the product and a dislike of personal appearance when wearing them. The fundamental requirement to protect the greater trochanter naturally requires a certain thickness of material (shock absorbing or energy shunting) to be placed over this area. The visual bulkiness of this padding certainly contributes to the dislike of personal appearance, as demonstrated through participant feedback gathered by Sims-Gould et al. (2014). In an interview, a resident commented that, “if they’re wearing slacks, they bulge out the side of the slacks, and it doesn’t look pretty”. Another resident was more scathing, adding, “It’s making you look bigger than what you are. Those things look hideous on some people”. The authors observed staff awareness of the aesthetic issues too, noting that female staff, in particular, could see the concerns for older women who felt that hip protectors made their hips look wider and overweight. Doherty et al. (2004) also noted that female care home residents were put off by the masculine appearance of underwear hip protectors.

Tavener-Smith and De Vet (2006) conducted in-depth interviews with hospital outpatients prescribed hip protectors. They found the most prevalent theme was that underwear hip protectors were perceived as a garment of clothing worn within domestic routines of getting dressed, using the bathroom, and other ordinary daily activities. In this respect, physical frailty makes usage difficult. An 83 year old lady commented, “I found them very difficult to put on. I couldn’t get them up. I did manage to push them down to get them off, this is the main issue with me”. The difficulty associated with putting on and taking off hip protectors can impact on the independence and autonomy of the user. Care home residents who were otherwise able to use the toilet independently found that they couldn’t when wearing hip protectors (Ledsham et al., 2006; O’Halloran et al., 2007). Van Schoor et al. (2002) identified studies where hip protectors have actually contributed to falls for this very reason. For example, Cameron and Kurrle (1997) reported on a woman with Alzheimer's who suffered a hip fracture after falling whilst trying to use the toilet during the night. The hip protector appeared to be around her knees at the time.

The practical aspect of underwear holding the protective pad closely to the hip cannot be ignored but the attempt to hide the protection under clothing perhaps also reflects a perceived sense of embarrassment or shame linked to ageing and loss of independence. This perception may also contribute to a lack of understanding or acceptance of fracture risk, where elderly people are not prepared to accept the need to wear hip protectors. Sims-Gould et al. (2014) note that even care home residents who appear frail don’t recognise the need in themselves. However, they are able to recognise other residents who are very frail and unsteady and “really need them”. This illustrates how hip protectors are synonymous with increased dependency and frailty for those who wear them, and naturally there is reluctance to be identified within that group. As Tavener-Smith and De Vet (2006) put it, the perception that hip protectors reduce autonomy is, “a powerful deterrent to continued use in a population where independence is paramount”.

The positioning of hip protectors solely within a medical care context appears at odds with the practical reality of these products as items of clothing, worn within daily routines. The clothes we wear are loaded with meaning tied to our personal identity, sense of self, and how we ‘fit in’ with others. Designing a hip protector that meets a user’s psychological needs is rooted within the

subjective pursuit of understanding this meaning. If hip protectors are broadly perceived as garments it is understandable that they are subjected to the same visceral judgement we might apply when pondering the rails at a clothing retailer, i.e. how does it look and feel when I try it on? Is it 'me'? With this in mind, the broadly utilitarian aesthetic, lack of variation in colour and shape, and dominance of underwear style hip protectors, may all contribute to a dislike of current hip protector designs. This point is reinforced by Topo and Iltanen-Tahkavuori (2010) who examined how clothes provided by hospitals and other care institutions construct a notion of 'patienthood' as materialised ideology. Although the work looks more broadly at clothing worn by patients in care environments the principles discussed are easily applied to hip protectors. The authors argue that wearing patient clothing is a process of giving up control and identity. They reflect on the 'otherness' of patients' status that is underlined by the use of institutional clothing. They have developed a framework to distinguish between clothes that represent normality and clothes that represent otherness (see Table 2). This is very useful when viewed with respect to hip protector design, where characteristics, such as being in accordance with cultural norms of clothing, aesthetics, usability and comfort, all resonate with barriers to acceptance and adoption established in other literature.

Table 2. Features of patient clothing along the dimension of normality and otherness. Adapted from Topo and Iltanen-Tahkavuori (2010).

Normality, continuity	Otherness, discontinuity
Clothes…	Clothes…
• are in accordance with gender specific cultural norms of clothing	• are not in accordance of cultural norms of clothing
• protect one's privacy	• are revealing and infantilising
• conceal illness and disabilities	• highlight and stigmatise disabilities
• support or enable independence	• prevent active involvement or action
• have a familiar appearance and are aesthetically appealing	• have an "ugly" or odd appearance
• are easy to put on, pleasant to wear	• are uncomfortable to put on and to wear
• fit the wearer	• are the wrong size, do not fit the user appropriately
Signals moral competence and situational control	Signals incompetence and inability, and loss of situational control

4.2 Hip protector market and garment design

The review of online sales material reinforces the view of underwear hip protectors as garments by embracing the notion that 'fashion' is synonymous with youth. It seems deeply ironic that, for a product primarily designed for a broad ageing population, the vast majority of hip protectors are photographed on young, female bodies. Discourse concerning perceptions of body types, and the notion that hip protectors on 'attractive' bodies can increase sales, is beyond the scope of this paper. However, the way these products are marketed online brings into question who the intended purchasing audience is. For example, Mobility Smart, Medipost and Betterlife (part of the Lloyds

Pharmacy group) are three online retailers operating in the UK whose sales images of hip protectors are presented this way. They are typical of the type of hip protector suppliers found globally and provide a wide range of care-related products. Their target audience is wide, selling to individual consumers, but also to health care professionals and institutions. In this respect, choosing a hip protector may be out of the control of the individual who is expected to wear it, for example, purchased by a concerned relative or supplied by a care home. The loss of agency this represents could quite understandably lead to barriers to acceptance of hip protectors.

Underwear hip protectors dominate the market, including wrap around styles that are easier for carers to help frail people with limited mobility to put on and take off. However, hip protectors worn over clothing are also available, consisting of a belt which extends in width over the hips, with integrated soft or hard shell impact protection. There is little research into the preferences between hip protectors worn under or over clothing and further investigation into the prevalence of underwear style hip protectors is needed. Greater comfort, ease to put on and take off, less requirement for laundering, and less interference with incontinence products, seem like potential advantages to hip protectors worn over clothing. However, whilst investigating factors influencing hip protector use in community-dwelling older adults, Blalock et al. (2010) compared four different designs, three of which were underwear type products, but one was the HipGuard product worn over clothing. They found that factors relating to comfort and appearance were most disliked in the product worn over clothing compared to the underwear products. Perhaps the appearance of this type of product is susceptible to greater scrutiny as it is visible when worn. It may also be more uncomfortable if worn in bed, as was the expectation in this study. Further investigation is needed into attitudes towards hip protectors worn over clothing and the contexts where this style may be preferable to underwear products. This includes new hip protector designs with airbag technology integrated into a belt worn over clothing.

4.3 The cost of hip protectors

Hip protector products are expensive (retail prices range from about £22 to £99), especially compared to ordinary underwear, so it is surprising that cost is not reported more frequently as a barrier to initial acceptance. Many of the intervention studies reviewed (e.g. Bentzen et al., 2008a; Blalock et al., 2010; Cameron et al., 2011; Forsén et al., 2004) accessed funding to provide the hip protectors for free. In reporting rates of acceptance and adoption, the researchers do not also ask participants if they would continue using hip protectors if they had to pay for them themselves. In an American study, Burl et al. (2003) describe the cost of hip protectors as a “major barrier”, and recommend that health insurance providers cover the expense, arguing that would be more cost effective than covering treatment for hip fractures. Similarly, Honkanen et al. (2006) describe how nursing staff are discouraged by the cost of hip protectors with concerns that resources allocated towards them would be diverted from other important institutional programs. Over half of the participants interviewed (n=10) by Tavener-Smith and De Vet (2006) lived at home providing useful insight in attitudes towards hip protectors outside an institutional context. Costs were identified as a key concern to those living solely on their pension. An 83 year old Australian lady insisted that, “I can’t see the money in them. I can’t for the life of me… nearly $A100 for two pairs of pants and two hip things”. In the UK, hip protectors are shown on the NHS supply chain website but the pressure on budgets well reported in the media limit their prescription to only the highest risk individuals.

The cost of the hip protectors studied by Laing et al. (2011) was investigated through suppliers online, ascertaining the lowest retail cost currently available. The authors only investigated the effects of pad geometry and material properties on the biomechanical effectiveness of 26

commercially available hip protectors they chose as a broad representation of the products available. There is no direct correlation between retail cost and hip protector efficacy, with examples of lower cost products having greater biomechanical effectiveness than higher cost ones. Of the examples reviewed, the visually slimmer hip protectors, with less bulky padding, offer lower levels of impact protection than other products with thicker pads. The less bulky appearance may make the products more visually appealing, but the perceived sophistication this brings also commands a higher retail price. For example, three of the slimmer hip protectors, Bort, LYDS and WonderHips, are priced between £50 and £70 per product, representing the more expensive end of the market.

5. Reflection

Hip fractures are a very serious condition in the elderly which can severely impact on quality of life and lead to an earlier death. Hip protectors are shown to be effective at reducing the risk of hip fractures, particularly in care home populations. Many barriers exist, relating to the design of hip protectors, preventing acceptance and long-term compliance. The lack of discourse on this topic within the design research community presents a unique opportunity for further research in this domain. Hip protectors are garments, but the academic interrogation of these products as designed fashion items is non-existent. Discourse concerning the design of hip protectors largely focuses on engineering and technical factors. However, a broader philosophical enquiry, underpinning a human centred design approach, and dealing with issues relating to semantics and identity is clearly long overdue.

The next step is to transition from the ‘discover’ to the ‘define’ phase of the double-diamond informing a design brief for new product development. This will include gathering the views of elderly participants through focus groups to understand what is perceived as acceptable, in terms of aesthetics and function, and expectations of product cost. The potential for co-design strategies with elderly people and healthcare professionals will also be investigated as part of this process. Statistically, women are at greater risk of hip fracture than men but analysis of attitudes and expectations towards hip protectors by gender is very limited. This will be an important part of further work examining the potential of hip protectors as lifestyle products rather than simply a medical intervention.

6. Conclusion

As the opportunities for human-centred design research are developed, this critical and contextual review underpins some key themes to explore with potential hip protector users. Protective clothing offers no protection if it is not worn, therefore receptivity is the key to eventual compliance. In order to foster long-term acceptance, design criteria including aesthetics, convenience, comfort and cost should be as important as the level of hip protection. Greater variety may be sought, responding to an adaptive design language based on identity and context, e.g. active ager or very elderly, masculine or feminine, colour, style, etc. Further motivation might be necessary to create long-term acceptance, such as hip protectors that enhance physique, improve proprioception, or have health monitoring capabilities. Finally, to promote earlier adoption within ‘at risk’ populations, could hip protectors be seen as a positive active ageing symbol, a self-statement of independence and healthy, active living?

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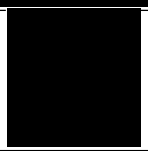
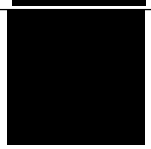
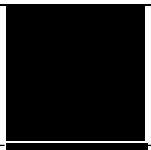
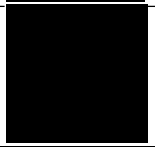
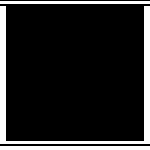
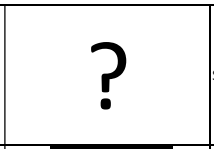
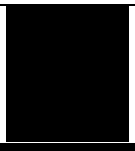
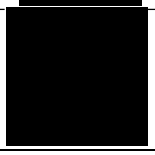
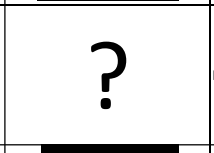
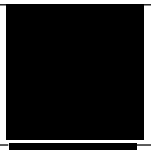
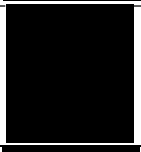
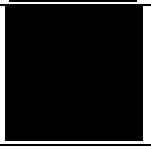
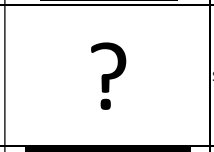
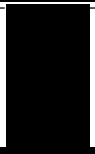
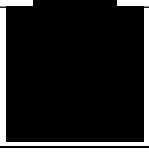
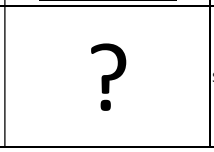
Acknowledgements: this research is supported by the 3D3 Centre for Doctoral Training, funded by the Arts and Humanities Research Council. The PhD studentship is fully-funded from the National Productivity Investment Fund. Many thanks to my supervisors, Dr Simon Clarke and Drummond Masterton, for their continued guidance and support.

8.3 Appendix C - A review of the hip protector garments whose protective pads were studied by Laing et al. (2011)

A review of the hip protector garments whose protective pads were studied by Laing et al. (2011). There is no direct correlation between retail cost and hip protector efficacy, with examples of lower cost products having greater biomechanical effectiveness than higher cost ones. Note – prices from overseas suppliers converted to Pound Sterling at mid-market rate on 3rd March 2024.

	Hip Protector	Manufacturer	Image	Pad Type	% Impact Attenuation at 3 m/s	Online Cost £ (March 2024)	Web Retailer
1	HipEase	Patterson Medical/ Sammons Preston		Soft	40	£23.74	https://www.rehab-products.com/products/hip-ease
2	HIPS	Qvortrup Medical A/S		Hard	37.1	£118.97	https://www.mobilityworld.co.uk/products/hips-combined-hip-protection-system
3	KPH	Medlogics		Hard	36.6	N/A	https://www.amazon.co.uk/Protector-Pair-Pants-1Pair-Protectors/dp/B074J1NJW8
4	Pelican Super Soft	Pelican Manufacturing PTY Ltd		Soft	30.2	N/A	
5	Safehip Air-X	Tytex A/S		Soft	26.6	£72.00	https://www.medipost.co.uk/product/safehip-airx-unisex-hip-protectors/?attribute_pa_size=medium
6	ProtectaHip+Plus	Plum Enterprises INC	?	Soft	24.5	N/A	
7	Hipsaver	Hipsaver		Soft	23.5	£46.39	https://www.win-health.com/hipsaver-nursing-home-soft-hip-protector.html
8	Posey Regular	J.T. Posey Company		Soft	23	£64.59	https://www.alimed.com/posey-hipsters-standard-briefs.html
9	Anatech	Anatech		Soft	22.6	£65.18	https://www.homehealthcareshoppe.com/anatex-hip-protector-wrap-small-medium-large
10	ProtectaHip	Plum Enterprises INC		Soft	22.5	£102.67	https://plumenterprises.com/product/plums-protectahip-general-use-hip-protectors/
11	Hip Guard	HipGuard Ltd	?	Hard	22.2	N/A	
12	Caresse	Remploy Healthcare	?	Hard	22.1	N/A	
13	Secure	Personal Safety Corporation		Soft	21.3	£31.60	https://www.securesafetysolutions.com/HipProtectors_SHP.htm

14	Pelican 179P	Pelican Manufacturing PTY Ltd		Soft	20.2	N/A	
15	Alimed Hip Shield	AliMed		Soft	20	£42.07	https://www.alimed.com/alimed-hipshield-hip-protector.html
16	Pelican Washable	Pelican Manufacturing PTY Ltd		Soft	18.9	£61.34	https://www.pelicanmanufacturing.com.au/product/hip-protectors-individual-standard-pants-and-or-pads/
17	Safehip Classic	Tytex A/S		Hard	17.5	N/A	
18	Posey Heavy Duty	J.T. Posey Company		Soft	15.4	£54.91	https://www.vitalitymedical.com/posey-hipsters-standard-brief.html
19	Hornsby Comfy Hip	Hornsby Comfy Hips Pty Ltd		Soft	15.1	£21.00	https://hornsbycomfyhips.com.au/products/unisex-protective-underwear-with-pockets?variant=40540596797632
20	Hip Shield	Promedics		Soft	12.4	£60.25	https://www.mobilitysmart.co.uk/hipshield-hip-protector-female.html
21	FallGard	FallGard		Soft	12.4	N/A	
22	WonderHip	Vital Base A/S		Soft	12.2	£68.93	https://www.sitz.dk/shop/p/style-01-mlskh/p/style-01-mlskh
23	Bort	Bort Medical		Soft	10.2	£34.99	https://www.vitego-shop.de/bandage-thigh-hip-bort-stabilohip-hip-protector-medium
24	LYDS	Comfortable		Soft	10.1	£53.60	https://www.comfortable.nl/healthcomfort/heupbescherming/comfort-hip-protector-single-pack/
25	ComfiHips	ComfiHips LLC		Soft	7.5	£82.95	https://www.pharmathera.com/comfihips-hip-protector-set-brace-for-women
26	Impactwear - Flexible	Impactwear		Soft	2.5	N/A	

8.4 Appendix D - Transcript of interview with Tony Ka Yui Wang

Transcript of interview with Tony Ka Yui Wang, Managing Director Bodywear Lab. Recorded 25th July 2024.

This interview took place after the PhD viva as a required amendment to the thesis to demonstrate a greater awareness of garment technology relating to intimate apparel.

Wang: I've got a few points that's worth you exploring: With the fabric side, you can look into the modulus of fabric. That is how much give a fabric has when it comes to the performance of the fabric on body. So, a higher modulus means that you can… It will control the body better. Another thing to bear in mind is the weight of the fabric. So different grams per meter square. That's another thing… typically a high impact active wear bra would use a higher weighted fabric for the control. So that typically ranges between 150 gram up to 250 gram, which will give you that sort of control. And then the other kind of the final thing that could have an impact to the quality of the product is how you place the stretch direction of fabric. So fabrics, in this case, tend to be knitted when it comes to what I'm understanding your project is. It's more like a stretch product that is put onto someone, so it needs to have give, and in terms of a fabric row when it's being knitted some fabrics stretch more one way than the other.

Researcher: Yeah.

Wang: So it's then how you place that stretch onto the body. And a general approach from a contour point of view, let's say a swimwear or leggings, is to have stretch around the body.

Researcher: OK.

Wang: Now that is open for exploration, because from a medical point of view, you might actually want to put the stretch the other way around, so that requires some testing.

Researcher: OK. So, the stretch around the body is just in terms of a… from a sort of compression perspective to kind of keep…?

Wang: Yeah, compression and ease of putting on and off the garment. Because let's say identical circumference leggings, with the stretch direction horizontally and vertically, would have an impact on how easy it is to put on and off.

Researcher: Yeah.

Wang: And then while it's on, how it functions.

Researcher: Yeah, I see. So, with the example of the leggings, if you've got the stretch direction long ways, you could be pulling and pulling and pulling trying to get them on and it's not going up your leg.

Wang: Exactly.

Researcher: Yeah, that makes a lot of sense.

Wang: Exactly, but some manufacturers, or some brands, actually put the stretch vertically for benefits such as 'bum lifting'… because of that.

Researcher: Yeah. OK, right.

Wang: So it kind of varies. So, this will be an approach where you have to go in from an almost medical point of view.

Researcher: Yeah. I think in my context… it certainly, I think, would make more sense to have the stretch direction around the body rather than vertically.

Wang: Yes.

Researcher: Yeah. OK.

Wang: Yeah, I would say so as well.

Researcher: OK, OK. Do you mind if I share on the screen what I've been working with to perhaps get a little bit more insight.

Wang: Of course, go for it.

Researcher: Yeah. OK. This is under NDA but Nicole has signed an NDA on behalf of the company.

Wang: Yes, yeah, yeah.

Researcher: So, hang on. There you are. Well, this is actually directly from the thesis. Just as a bit of context, so these are the typical types of protective, hip protector type underwear.

Wang: Yeah.

Researcher: And as you can tell, there's very much an emphasis on the functional aspect from a from the protection aspect. So, Tytex are one of the biggest brands who are doing these sorts of products.

Wang: Yeah.

Researcher: And the emphasis on my project has been… in order to sort of encourage more people to want to engage and be proactive in terms of protecting themselves as they age….

Wang: Yeah.

Researcher: So how can you kind of, I guess, change the… our perception and the kind of visual language of these products to make them more appealing.

Wang: Yeah.

Researcher: And one of the ways I've been looking at is around reframing what it means as a garment. So rather than having a kind of medical sort of context and a garment that expresses vulnerability and decrepitude, you know, how do you shift that conversation to one which is very much more about being active and mobile and being proactive about aging?

Wang: Uh-huh. Yeah. Agree. Yeah.

Researcher: And a big focus on women especially because of the greater instances of osteoporosis in women and risk of hip fracture from that perspective.

Wang: Mm-hmm.

Researcher: So that's kind of a bit of the kind of background context.

Wang: Yes.

Researcher: What I ended up in the end looking at was a… where it ended up was in this kind of space here. So, I was looking at kind of a shift from the underwear garment to something which is worn on the top half. There were some practical considerations around that in terms of and it being easier to use sort of day-to-day things like…

Wang: Yeah.

Researcher: So going to the loo for example, but also to kind of change the, I guess the perspective on what it is as a garment.

Wang: Mm-hmm. Yes.

Researcher: So I have been looking at ways in which you can make it look like a kind of base layer or kind of activewear top but extending the lower hem down past the waist...

Wang: Mm-hmm.

Researcher: And over the hips and bum and building in the protection that way.

Wang: Yeah. Yeah.

Researcher: So this was a kind of earlier iteration of that as a concept and it's kind of… this was the kind of concept that I've really sort of took forward through the project.

Wang: Mmm.

Researcher: I did quite a lot of work looking at the protective element itself and have done quite a bit of research around 3D printing in flexible lattices as an energy absorbing material.

Wang: Yes. Uh-huh. Yeah.

Researcher: But ultimately the product kind of ended up in this sort of space. So sort of fairly kind of similar but with a kind of an internal pocket in which the pad can be located.

Wang: Yeah.

Researcher: I was thinking about maybe using materials like silicon backed fabric and.

Wang: Yeah. And looking for to grip because it will ride up without that, yeah.

Researcher: Yeah, yeah, yeah. And on that point of riding up, I mean, I was thinking that although… so there's this scenario where you could have this sort of over, you know over clothes. But I was thinking primarily it'd be something that would be tucked in. So you could tuck it into like a layer underneath, maybe underwear, or just tuck it into sort of lower half for that very reason to sort of help kind of keep that sort of pad stability.

Wang: Yeah.

Researcher: And so yeah, I was… I guess from your perspective, just looking at this sort of cold, if you like, I wondered whether there was… if anything that that you could see here where you think there's a real opportunity to think about constructing it this way or to use this particular type of fabric or to think about how the stretch maybe orientated this way or that way in terms of giving it a little bit more benefit?

Wang: Yeah. Umm, so I think like you said, the first point that I would mention is the issue of the product riding up. But I think you've already covered that by having it either over the body or being tucked under a pair of trousers or leggings, but I think in practice that might still ride up or down. So, it could be an approach where you actually also develop something to go under, let's say a leggings with keyholes on the side where you can fit that on, or even Velcro tape that works hand in hand to keep the protective foam layer in place.

Researcher: Yeah. Mm-hmm. Yeah.

Wang: That's something to take into consideration.

Researcher: That was definitely something I was I was thinking about like whether if there's a kind of underwear set, for example, that goes with it, that helps to anchor it. I was even thinking about maybe an alternative could be a sort of leotard type fastening as well to kind of anchor it in the right place.

Wang: Yeah. Exactly. Yes. Yeah.

Researcher: I did do some trials with some younger participants where they did do a kind of user evaluation. So had some mock ups produced and there was certainly an issue around it riding up, but perhaps not as much as you might expect.

Wang: Mmm.

Researcher: So it's kind of fairly encouraging and in this iteration, it was very much designed with… So the material… can't see it in this photograph, but the material kind of did go right down underneath the backside as well.

Wang: Uh-huh.

Researcher: So I think that really did help with the kind of location.

Wang: Perfect. Yeah.

Researcher: Yeah, yeah, yeah.

Wang: I think in in terms of the cuts and style line of the product itself, it's actually really well designed because all the… cause your aim was to make it so that it doesn't feel like a product aimed for that reason. Whereas this, you've kind of nailed it in terms of how well the protector layers is placed. In terms of material, another spin that you could take is from a wellness perspective.

Researcher: Alright.

Wang: Sorry, I don't know if you know that some fabric can actually be infused with qualities such as like aloe vera or anything that could then spin it into the Wellness sector.

Researcher: OK.

Wang: So it kind of hits two birds with one stone.

Researcher: Yeah. OK.

Wang: Tempting to think about.

Researcher: So aloe vera infused? That sounds amazing.

Wang: Yes. And we actually have… we've made swimwear here where aloe vera's infused into the layer so that the lining of a swimsuit is treated with that.

Researcher: That's really interesting. OK, thank you. And in terms of where you would look for, kind of I guess, new innovations… So as you just described that aloe vera infused fabric or any other kind of fibres and fabrics, is there a particular kind of resource that you use to sort of identify what's new and what's kind of coming into the industry at all?

Wang: Yeah. From our side, it's mainly from suppliers. So whenever there's new innovation, we will get sent brochures and like heads up emails saying that there's a new fibre coming in or like how fabrics are being developed.

Researcher: OK.

Wang: So probably go direct to fabric suppliers. That could help and if you want any direction in that I'm happy to share some more information or contact with you so that you can approach them, yeah.

Researcher: OK, really appreciate that. Thanks Tony. And just in terms of… so the context for this project is obviously our aging bodies…

Wang: Right.

Researcher: And so there's the other thing I've been asked to really consider more of is accommodating changing shape, in you know… as people age, how the body sort of changes shape.

Wang: Yeah.

Researcher: And I was wondering whether there was any other kind of perhaps pointers that you might sort of indicate in terms of what aspects of this garment might need the most sort of adjustment, I guess, to accommodate different body shapes?

Wang: Yeah. Have you thought about how this is being sized?

Researcher: That's a good question. And yeah, a little bit, I mean what's… I guess, what makes this different to how you, you know, how you might sort of look at off the peg sizing is obviously the positioning of the pads is really critical. One of the things I'm looking at is 3D scanning, 3D body mapping, in order to generate data to produce bespoke or made to order garments which kind of feels like perhaps the sort of failsafe option in terms of positioning.

Wang: Yeah. Mm-hmm.

Researcher: The other thing I was looking at was whether it could be… the overall garment could be sized through… So, if this was like off the shelf like it could be sized through, you know, a kind of general kind of retail sizing system, but maybe there could be another kind of dimension added to it in terms of… If you took someone's seated height, it would be a way of ascertaining the kind of torso length.

Wang: Yeah.

Researcher: So maybe from your head or from your shoulder down to the seat surface to get a sense or to get a measure of where the length of the torso in relation to shoulders to hips in order to make sure that… so that the padding could be in the right place. So I envisaged potentially you could have… OK, so this is a size 16 vest, but it comes in a short to long body.

Wang: Yes. Yeah, yeah.

Researcher: So maybe there's three different like lengths, but in in an overall size. Does that… would that…?

Wang: Yeah, that's well thought through because my point on this note is actually the difference in torso length between person to person, which we in the industry see it every day where some client would want a longer torso product, someone shorter ones, and by doing this you're kind of avoiding the problem. A) this tank top almost like design isn't governed by your torso length, and B) if the pockets on the side can be made adjustable then you can still produce the product… you can still mass-produce the product in your standard body sizes, but with the option of how the pocket is being placed so that the user can then adjust or put the foam into the right layer that they know, OK, this is the right thing for me and I know I'm comfortable with the sizing because that's my body size.

Researcher: Yeah.

Wang: So from a manufacturer point of view, if mass production is something you would like, then I would suggest that keep the design as it is, but on the side panel, maybe have three different pockets as options and then that way your user can then adjust to where it fits and you could also like have a guide on where to place certain foam.

Researcher: OK yeah.

Wang: Yeah.

Researcher: That's really helpful. I mean, the other kind of fullback position I was thinking is if just the actual padded area is just more generous and that so there's more of it. One of the things I've really been focusing on is trying to design the material so it's as low profile as possible…

Wang: Yes.

Researcher: And actually that, you know, I've had some success with that using these 3D printed materials…

Wang: Mm-hmm.

Researcher: So you know if the really vulnerable bit of the hip joint, the greater trochanter at the top of the femur… if the padding is, you know there's a certain degree of redundancy in terms of where that is…

Wang: Yeah.

Researcher: Then then, that's obviously going to help as well.

Wang: Yeah.

Researcher: So yeah. OK. Right, thanks Tony. Any other sort of pearls of wisdom that you could send my way at all? Sort of final thoughts?

Wang: Alright. I will definitely be thinking about the project and whatever I can think of, any contact that I can think of, I will just send it your way. And I'll do a bit of an explanation just so that you're not just getting sent contact without context.

Researcher: OK. Yeah, I really would appreciate that.

8.5 Appendix E - Participant information sheets and consent forms

Participant information sheets and consent forms for interviews, focus groups and product user evaluation.

Participant Information

[Interview (non-clinical) v1]

Title of Research Project

Falls in the elderly: designing human-centred hip protection for older people.

We would like to invite you to take part in our research. Before you decide we would like you to understand why the research is being carried out and what it would involve for you. We will go through the information sheet with you and answer any questions you have.

What is the purpose of the study?

About 70–75,000 hip fractures occur annually in the UK. The average age of a person with hip fracture is 77 years and the annual cost of medical and social care for all the hip fracture cases in the UK amounts to about £2 billion. About a quarter of patients with hip fracture are admitted from institutional care, although 10–20% of those admitted from home ultimately move to institutional care. About 10% of people with a hip fracture die within 1 month, and about one third within 12 months (National Institute for Health & Care Excellence 2009).

The study will investigate materials and technologies that could be used as hip protection for elderly people. The emphasis will be on reducing the risk of hip fractures caused by unexpected falls. The research will focus on how hip protection can be designed to look, feel and operate, in a way that's sensitive to sociocultural and lifestyle aspirations of elderly people. The outcome of the research will include hip protector prototypes where both aesthetic and functional qualities can be evaluated. The research will be submitted as a PhD thesis at the end of the project.

Why have I been invited?

Your expert knowledge in the field of designing garments for older populations will provide useful insight to assist in the development of new hip protection design concepts that improve rates of acceptance and adoption.

Do I have to take part?

It is up to you to decide to join the research. We will describe the study and go through this information sheet. If you agree to take part, we will then ask you to sign a consent form. You are free to withdraw at any time, without giving a reason.

What will happen to me if I take part, and what will I have to do?

You will take part by being interviewed on the topic of designing garments for older people. The interview will be semi-structured and take approximately 45 minutes. During the process the researcher will take notes and the interview will be recorded using audio equipment. Your contribution to the research will be voluntary and no payment or reimbursement of expenses will be available.

What are the possible disadvantages and risks of taking part?

Potential risks are very minimal. Informed consent will be requested to publish your name and interview transcript as an expert in the research domain. After the interview, the audio recording and

transcript will be sent to you to verify your consent for it to be used. You may remove any part of the interview you do not wish to disclose or completely withdraw from the research. In such circumstances, part or all of the interview audio and transcript will be destroyed.

What are the possible benefits of taking part?

The feedback and insight you provide will be a highly valuable contribution to the development new hip protection design concepts. You will be able to read all published material from the research project, and the final PhD thesis. It is expected that hip protector prototypes, developed through the research, will form part of an exhibition towards the end of the project, which you will be invited to.

What happens when the research ends?

You are invited to keep in touch with the development of the research in relation to publications, exhibitions, and product development. Please indicate on this consent form if you wish for your email address to be retained to receive updates on the project progress.

What will happen if I don't want to carry on with the study?

You can withdraw from the study, for any reason, at any time by contacting the Researcher. If you do withdraw from the study, data previously provided will still be retained and used for the purposes outlined above.

What if there is a problem?

For further information about the research, please contact:

Simon Andrews, PhD Candidate 3D3 NPIF AHRC Studentship

School of Architecture, Design & Interiors, Falmouth University, Falmouth Campus, Woodlane, Falmouth, Cornwall TR11 4RH

Tel - 01392 370749

Email – simon.andrews@falmouth.ac.uk

If you have concerns/questions about the research you would like to discuss with someone else at the University, please contact:

Dr Simon Clarke, Director of Studies for the PhD

Fashion & Textiles Institute, Falmouth University, Penryn Campus, Treliever Road, Penryn Cornwall TR10 9FE

Tel - 01392 370493

Email – simon.clarke@falmouth.ac.uk

Will my taking part in this study be kept confidential?

The data gathered in the study will be stored digitally on an encrypted laptop and backed-up on a password protected USB stick which is stored in a locked draw at Falmouth University. Paper copies of notes or feedback will be scanned and stored electronically in the same way, and the originals will be destroyed. Your personal opinions and the researcher's observation of you will be central to the research and as such could be published as part of a research output. You will remain anonymous and your name, images in which you can be identified, and audio of your voice will not be published

without prior written consent. The data will be retained for future use but only for the further development of hip protection designs for the elderly. Your data will only be shared with the Research team directly involved with the study, which includes personnel from Falmouth University, DM Orthotics and Cornwall Care. The data gathered will not be used other than for the purposes described above and third parties will not be allowed access to it (except as may be required by the law). Your data will be held in accordance with the Data Protection Act.

What will happen to the results of the research study?

The research will directly inform the design development of hip protection for the elderly. Prototype designs will be presented alongside the research as part of an exhibition at the end of the project. The researcher and project partners will also investigate the opportunities for the commercial development of designed products. Parts of the research will be written and presented for publication in academic journals and conferences. The research project will ultimately be submitted for examination as a PhD thesis. You will not be identified in any report or publication without prior written consent.

Who is organising and funding the research and who has reviewed the study?

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Consent Form

Title of Research Project: Falls in the elderly: designing human-centred hip protection for older people

	Please circle
1. I confirm that I have read and understand the participant information provided dated..... for the research study. I have had the opportunity to consider the information, ask questions and I have had these answered satisfactorily.	Yes / No
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my legal rights being affected.	Yes / No
3. I agree to take part in the above study.	Yes / No
4. I agree for my name and profession to be used in research publications.	Yes / No
5. I agree to my participation being photographed, filmed and/or audio recorded.	Yes / No
6. I agree to photographs, film and audio recording taken during my participation to be used for research publication and other information dissemination, via a web site for example, to inform others about the project.	Yes / No
7. I would like my email address to be retained to receive updates on the project progress.	Yes / No

Name of participant: .....Date: …….

Signature: .....

Email: .....

Name of researcher: Simon Andrews…….Date: …….

Signature: .....

2 copies to be signed by both participant and researcher, one kept by each.

Participant Information [Interview v1.2]

Title of Research Project

Innovation in hip protector design: challenging function, meaning and context.

We would like to invite you to take part in our research. Before you decide we would like you to understand why the research is being carried out and what it would involve for you. We will go through the information sheet with you and answer any questions you have.

What is the purpose of the study?

The study will investigate materials and technologies that could be used as hip protection for elderly people. The emphasis will be on reducing the risk of hip fractures caused by unexpected falls. The research will focus on how hip protection can be designed to look, feel and operate, in a way that's sensitive to sociocultural and lifestyle aspirations of elderly people. The outcome of the research will include hip protector prototypes where both aesthetic and functional qualities can be evaluated. The research will be submitted as a PhD thesis at the end of the project.

Why have I been invited?

Your expert knowledge in the field of elderly care, falls in the elderly, and the risks associated with hip fractures, will provide useful insight to assist in the development of new hip protection design concepts.

Do I have to take part?

It is up to you to decide to join the research. We will describe the study and go through this information sheet. If you agree to take part, we will then ask you to sign a consent form. You are free to withdraw at any time, without giving a reason.

What will happen to me if I take part, and what will I have to do?

You will take part by being interviewed on the topic of falls in the elderly, hip fractures and hip protection. The interview will be semi-structured and take approximately 45 minutes. During the process the researcher will take notes and the interview will be recorded using audio equipment. Your contribution to the research will be voluntary and no payment or reimbursement of expenses will be available.

What are the possible disadvantages and risks of taking part?

Potential risks are very minimal. Informed consent will be requested to publish your name and interview transcript as an expert in the research domain. After the interview, the audio recording and transcript will be sent to you to verify your consent for it to be used. You may remove any part of the interview you do not wish to disclose or completely withdraw from the research. In such circumstances, part or all of the interview audio and transcript will be destroyed.

What are the possible benefits of taking part?

The feedback and insight you provide will be a highly valuable contribution to the development new hip protection design concepts. You will be able to read all published material from the research

project, and the final PhD thesis. It is expected that hip protector prototypes, developed through the research, will form part of an exhibition towards the end of the project, which you will be invited to.

What happens when the research ends?

You are invited to keep in touch with the development of the research in relation to publications, exhibitions, and product development. Please indicate on this consent form if you wish for your email address to be retained to receive updates on the project progress.

What will happen if I don't want to carry on with the study?

You can withdraw from the study, for any reason, at any time by contacting the Researcher. If you do withdraw from the study, data previously provided will still be retained and used for the purposes outlined above.

What if there is a problem?

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School of Architecture, Design & Interiors, Falmouth University, Falmouth Campus, Woodlane, Falmouth, Cornwall TR11 4RH

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What will happen to the results of the research study?

The research will directly inform the design development of hip protection for the elderly. Prototype designs will be presented alongside the research as part of an exhibition at the end of the project. The researcher and project partners will also investigate the opportunities for the commercial development of designed products. Parts of the research will be written and presented for publication in academic journals and conferences. The research project will ultimately be submitted for examination as a PhD thesis. You will not be identified in any report or publication without prior written consent.

Who is organising and funding the research and who has reviewed the study?

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Consent Form

Title of Research Project: Innovation in hip protector design: challenging function, meaning and context

	Delete as necessary
1. I confirm that I have read and understand the participant information provided dated..... for the research study. I have had the opportunity to consider the information, ask questions and I have had these answered satisfactorily.	Yes / No
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my legal rights being affected.	Yes / No
3. I agree to take part in the above study.	Yes / No
4. I agree for my name and profession to be used in research publications.	Yes / No
5. I agree to my participation being photographed, filmed and/or audio recorded.	Yes / No
6. I agree to photographs, film and audio recording taken during my participation to be used for research publication and other information dissemination, via a web site for example, to inform others about the project.	Yes / No
7. I would like my email address to be retained to receive updates on the project progress.	Yes / No

Name of participant: .....Date: …….

Signature: .....

Email: .....

Name of researcher: Simon Andrews…….Date: …….

Signature: .....

To be signed by both participant and researcher. The researcher will electronically scan the signed document and return the original to the participant.

Participant Information

[30/01/23 - Prototype Evaluation v2]

Title of Research Project

Innovation in hip protector design: challenging function, meaning and context

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We would like to invite you to take part in our research. Before you decide we would like you to understand why the research is being carried out and what it would involve for you. We will go through the information sheet with you and answer any questions you have.

What is the purpose of the study?

About 70–75,000 hip fractures occur annually in the UK. The average age of a person with hip fracture is 77 years and the annual cost of medical and social care for all the hip fracture cases in the UK amounts to about £2 billion. About a quarter of patients with hip fracture are admitted from institutional care, although 10–20% of those admitted from home ultimately move to institutional care. About 10% of people with a hip fracture die within 1 month, and about one third within 12 months. (National Institute for Health & Care Excellence 2009)

This research is part of a practice-based PhD project. The study will investigate materials and technologies that could be used as hip protection for people who are vulnerable to falls and fragility fractures. The emphasis will be on reducing the risk of hip fractures caused by unexpected falls. The research will focus on how hip protection can be designed to look, feel and operate, in a way that's sensitive to sociocultural and lifestyle aspirations of the wearer. The outcome of the research will include hip protector prototypes where both aesthetic and functional qualities can be evaluated. The development of prototypes is supported by DM Orthotics, Redruth, Cornwall. Participants will be contributing to non-commercial research that will be submitted as a PhD thesis at the end of the project. After completion of the PhD, the research may have future commercial value.

Why have I been invited?

We would like to get some feedback on prototype hip protector garments and you have been invited to get involved due to your interest and/or current learning in design. A convenience group of 4-6 participants (equal number of women and men) will be recruited from the Falmouth University student population. To reduce the risks during the evaluation process, were inviting participants who have good physical fitness and mobility, and who are not at any risk of falls or have any other vulnerabilities.

Do I have to take part?

It is up to you to decide to join the research. We will describe the study and go through this information sheet. If you agree to take part, we will then ask you to sign a consent form. You are free to withdraw at any time, without giving a reason.

What will happen to me if I take part, and what will I have to do?

The research aim is to gather user insights into the 'wearability' of the prototypes. In particular, comfort, ease-of-use (i.e. getting on, taking off, and wearing throughout the day), and attitudes towards the look of the prototype garment.

Before the evaluation can take place, you will be individually measured by staff at DM Orthotics and a bespoke prototype garment will be manufactured for you to wear. The garment is similar to a vest of T-shirt with a lower portion that covers the hips.

You will be asked to wear the garment for a full day and record your observations. A feedback form will allow you to describe your experience at specific points during the day: in the morning (putting on), during the day (wearability relating to walking, sitting, standing, etc), and in the evening (taking off). Once the garment is on and you're ready for the day, they will be asked to take one photograph of yourself to record what they are wearing and your outward appearance.

After you have completed the activity, a follow up focus group will take place where you and the other participants can share your experience of wearing the prototype garment and discuss opportunities for improvements to the design. The focus group will take approximately 1 hour and you may be asked to attend more than one as the project develops. During the process the researcher will take notes and the session will be recorded using audio and video equipment.

You will NOT be testing the efficacy of impact protection as part of this research, and prototype garments under review will contain a 'dummy' hip pad to represent material thickness and feel. This will provide minimal impact absorption and will NOT protect your hips if you fall on them.

When recording your experience through the feedback form, you can decide on the information you want to disclose. Similarly, if there are aspects of the experience you do not want to share in the focus group, you will be under no obligation to do so.

What are the possible disadvantages and risks of taking part?

Potential risks to participants are minimal. Only people in good physical fitness and mobility will be asked to participate.

You can withdraw from the research at any time. Informed consent will be gained at the beginning of the study and feedback will be anonymised and names will only be recorded in relation to signed informed consent. Focus groups will be conducted in a relaxed environment and participants will already be familiar with each other. A collaborative approach will be adopted with no pressure on individuals to contribute unless they want to.

Being fitted for the garment does require physical body measurements to be taken with a tape measure. This will be conducted with your consent by trained staff at DM Orthotics.

You will be asked to put on and take off the garment in the privacy of your own home. The garment is similar to a vest of T-shirt, so presents no increased risk to everyday activity. There is a risk that after some time wearing the prototype you may experience some mild discomfort, although this is unlikely. You can stop the activity at any time and remove the garment if you do not want to continue. At the end of the activity, participants will be provided with a sealed plastic bag to return the garment to the Researcher.

Due to the potential future commercial value of the research, the prototype you evaluate is confidential. You will be asked to sign a non-disclosure agreement before taking part in the research.

Your contribution to the research will be voluntary and no payment or reimbursement of expenses will be available. When providing your consent to be involved in the study, you will waive any claim to intellectual property relating to the research.

What are the possible benefits of taking part?

As someone with an interest in, or learning about design, taking part will give you the opportunity to engage with a professional, people-centred design project. The feedback and insight you provide will be a highly valuable contribution to the development new hip protection design concepts. You will be able to read all published material from the research project, and the final PhD thesis. It is expected that hip protector prototypes, developed through the research, will form part of an exhibition towards the end of the project, which you will be invited to.

What happens when the research ends?

You are invited to keep in touch with the development of the research in relation to publications, exhibitions, and product development. Please indicate on the consent form if you wish to receive email updates on the project progress.

What will happen if I don't want to carry on with the study?

You can withdraw from the study, for any reason, at any time by contacting the Researcher. If you do withdraw from the study, data previously provided will still be retained and used for the purposes outlined above.

What if there is a problem?

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could be published as part of a research output. You will remain anonymous and images in which you can be identified, and audio of your voice will not be published without your consent. The data will be retained for future use but only for the further development of hip protection designs. Your data will only be shared with the Research team directly involved with the study, which includes personnel from Falmouth University and DM Orthotics. The data gathered will not be used other than for the purposes described above and third parties will not be allowed access to it (except as may be required by the law). Your data will be held in accordance with the Data Protection Act.

What will happen to the results of the research study?

The research will directly inform the design development of hip protection for people who are vulnerable to falls and fragility fractures. Parts of the research will be written and presented for publication in academic journals and conferences. The research project will ultimately be submitted for examination as a PhD thesis. You will not be identified in any report or publication without prior written consent. The researcher and project partners may in the future investigate the opportunities for the commercial development of designed products.

Who is organising and funding the research and who has reviewed the study?

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FALMOUTH
UNIVERSITY

RESEARCH CONSENT FORM

Title of Project: Innovation in hip protector design: challenging function, meaning and context. Prototype evaluation.

Researcher: Simon Andrews

Department: Fashion & Textiles Institute

Contact details - Email: simon.andrews@falmouth.ac.uk - Telephone: 01326 370749

Supervisor's Name: Simon Clarke

Supervisor's contact details - Email: simon.clarke@falmouth.ac.uk - Telephone: 01326 370493

It is important to Falmouth University, that you fully understand the purposes of the 'Innovation in hip protector design' research, what is involved, and that you are happy to take part. Once you have read the provided information sheet, please tick each box below to indicate your agreement and consent to each statement:

		Please tick relevant box/es below
1.	I confirm that I have read and understood the Participant Information Sheet dated 30/01/23 (Version: Prototype Evaluation v.2)	☐
2.	I have had enough time to consider the information and ask any questions I might have, and I am satisfied with the answers I been given by the above named researcher.	☐
3.	I understand that anonymised (i.e. not identifiable) versions of my data may be archived and shared with others for legitimate research purposes.	☐
4.	I understand who will have access to personal data provided, how the data will be stored and what will happened to the data at the end of the above named project.	☐

5. I understand that data collected during this study will be processed in accordance with data protection law as explained in the Participant Information Sheet (dated 30/01/23, version: Prototype Evaluation v.2) ☐

6. I consent to my participation being photographed, filmed and/or audio recorded understand how images and recordings will be used in research outputs. ☐

7. I understand that my participation is voluntary and that I am free to withdraw at any time without giving a reason. ☐

8. I agree to waive any claims to intellectual property that arise from the study. ☐

9. I agree to take part in the above study. ☐

10. I would like to receive email updates on the project progress. ☐

Name of Participant:…… Date:…… Signature:……

Name of Researcher: …… Date:…… Signature:……

Note: *When completed, one copy to be given to the participant, one copy to be retained in the study file.*

8.6 Appendix F - Transcript of interview with Fanny Karst

Transcript of interview with Fanny Karst. Recorded 26th September 2018.

Researcher: Can you tell me about your background and motivation to design clothing for older people?

Karst: Yes, so actually it's really a subject with you because I started… I come from a family where, you know, the older people, the people in the family are the most important people. So we always revere our grandparents and our great aunts and uncles. We have a lot of respect for them, and we took a lot of care, we took care of them in a practical way. We were really educated to take care of them. So I took a lot of care of my grandmother who had become very fragile with age, and actually, she broke her hip falling and she had very thin – you know – skin and her circulation wasn't amazing. So she would be bruised, she would have the darkest bruise, a huge bruise from – you know – brushing a table or something. So she had circulation problems and things like that, so she was pretty fragile, and certainly towards the end. So going back a little bit, even before I started studying fashion I always felt a little bit guilty for doing clothes, because it didn't really have any…I think there's enough clothes in the world, for sure. I didn't need to add anything else. But I was always attracted to old age and I really thought that no-one – you know – was looking after them or taking – you know – or putting a little bit of a light on them. And I admired, I've always admired older people and the way they dress, how they talk and their attitude and charisma, so even before I started St. Martins I had this idea that I was going to make clothes for old people and throughout my studies, once a year – because I couldn't do it for every project – I would do a project that was either dedicated to my grandmother, or to artists I admired, or people in old age. And then my final show, which was in 2007, was dedicated to – I had six older models who walked the catwalk – some of them were friends of my mum, a couple of professional models, and everyone I could find. But a couple of them were actually with a cane, with a walking stick. And that's how it started, so I think now, 10 years after, I'm still as interested, every day, in clothing for older people. It's really what I specialise in and I'm trying not to give in, in this sense that it's a project for everyone. It's completely a project for old people, the older the better.

Researcher: That's lovely! It sounds like that motivation is very deep seated, right from your childhood then. It's kind of like something which you… that kind of connection with older generations and understanding the value they can bring to society, and the lessons that can be

learnt, and all those. There's a really…a really wholesome narrative that comes out of that which I think is really nice to hear.

Karst: Yes and also I find that when you're in your twenties, and even now I'm in my thirties, I find I have a lot in common with people who are over 60 or 70 because by the time you get rid of your children, and you have some kind of pension and you don't… you're kind of retired, it's really what… it's what I find is kind of a second youth. So you've got the freedom pass, you can travel on the tube and the bus for free, you have all these perks about being old. And I think, people who enter that age with such a pessimistic view: "oh, we're getting old!" or something, but I think it's an age that brings a lot qualities and freedom. And you can say whatever you want, wear whatever you want – you know – without the pressure of society, or having a job, of having to raise children. I don't know, I think it's a great age to really be wild and free.

Researcher: Yeah, I think that's very interesting. It's almost like a kind of re-birth when you go into that…

Karst: Yes, second teenager, I think.

Researcher: Yeah, but of course the lovely thing about that as well is, at that age you've lost all those awkward – you know – social anxieties and things – you know – hang ups you might have had growing up. You've gone through all that and you're kind of like: "I can just do what I want and say what I want and it's all OK!". So, that's very interesting. Cool. OK, great. You obviously work with older clients. What do they perceive is wrong with clothing offered by retailers? Do they come to you specifically because there's nothing they like that they can find on the shelf, or…

Karst: Well, not really actually. I've learnt a lot of things throughout my 10 years of working. One, is that there's a huge taboo with ageing, so I don't think that older people are attracted to brands that are trying to promote – you know – like, older models and things like that, or trying to promote it as… you know, it used to be call 'Old Ladies Rebellion' and I think there was a rebellion from the ladies to this name. They hated the kind of idea that I specialised in old people, so there's a real resistance to that which I find that now I've gone around it, it's very complicated for me because on the one side I want to say that it's for old people, but on the other side I can't because they're not going to want to be dressed in something that specialises in old people. You see they never feel that they're old enough, which I completely understand. So, my way around it, which is a little bit complicated and it doesn't work all the time (in fact it doesn't really work) but it's to make my clothes and the concept so cool that they actually look forward to it. You know, so it's like, "ah, I want to be part of that group. I want to be part of the club". You know, the irreverent old ladies cool club,

so I make it as cool as the brands who are trying to be useful. So it's kind of the opposite, so I think that's the way round it. I don't know if that makes any sense.

Researcher: Yeah, I think that's right. I've been reading quite a lot around the associations with ageing and dress. And one of the things that really struck me was, perhaps, especially for older women getting to an age where, on the one hand, you don't want to be dressing too young but on the other hand you don't want to be dressing too old, and it feels like there's this kind of gap in the middle where…

Karst: Yes, no, it's very complicated but you see, I think a lot of things have changed. For example, I did my thesis on that as well at St. Martins, it was like, "can you be eighty and still be cool?". But what I find, so you have, for example, in the forties, older people after the war, people, you were old at like forty and you would wear these kind of black clothes, you know, pencil skirt, do your hair, it was very different. But then the kind of baby boom generation, which is my parents' generation, or my mother's certainly, they were young in the sixties and seventies. They wore jeans, they smoked, they listened to rock and roll, and they went a little bit wild, and so I think they age exactly how they have lived. So my mother has worn jeans, and like, trainers and t-shirts and shirts all her life, and now she's 74 and she still wears, kind of, trainers, jeans and t-shirts or shirts, so in that sense nothing has changed. So I think being an old person, you know, forty years ago is very different. You know, the concept we have of an old lady, with her little bag and little black shoes, you know, is a little bit gone. And you know the way that old ladies used to do… no, people used to do their hair all the time in the fifties and things. So the older people now, they still do the hair and the thing in a certain way, but I think it's about to change and for me, thinking how I'm going to get old, I think I will dress more or less the same, except… and then we'll get into that you kind of start covering some stuff or, so yeah… So that's on the concept side. Psychologically they don't want to be perceived as old, they just want to blend in. So it's not about looking young or looking old, it's about kind of blending in and having the kind of clothes that correspond to your lifestyle.

Researcher: Yeah, that's really interesting and I totally understand your point there about the way in which you actually… you have a… it's more about a style that you're comfortable with and you… it doesn't matter what – you know – what age you are, if that's what you've kind of grown with and aged with then that kind of makes sense that it's just something that carries through. And that kind of coded design language of different kind of generations' clothing is… seems to be very much diluting and I think that's… yeah, I can really understand where you're coming from there, that's really interesting.

[short interruption to clarify the audio is still clear]

OK, so I think you might have picked up a little bit on this [already] but the third question I was posing there is: is there a particular design language that you adopt which is consciously different to an approach for younger audiences? Maybe you've already kind of started to answer that question, but could we just look at that?

Karst: Yes, yes. Well it's very complicated and it's obviously something that I really don't master. You see, I didn't study marketing or business so sometimes I get these things wrong. But also, like once you start being too aware of the language you use and – you know – the message you're spreading, if you're too particular or nervous about it, it doesn't come across as genuine. So I feel – and I make mistakes every day – but I try to be as bold and strong message as I can in a way to break a little bit the taboos and just to say how it is, but in an elegant way compared to using the kind of appropriate language. I don't know, I like to be a little bit provocative and humorous about these things because… but of course we will get reaction and I get reaction from ladies saying it's amazing and some others saying, "well, how dare you?", so, but I try to be subtly provocative. You know, I do the t-shirts with the messages and that's surprisingly… I mean it was not all my taste. You know, 'old is the new black' is not really my idea, but it has been a great success and people love it. And what we find now is that we have ladies emailing me every day to say, "I got stopped in the street ten times with the t-shirt one day". So I think there's a lesson to be learnt that they want to be noticed and to be put on a pedestal, and if you can do that in kind of a chic way, they're going to love it. So we've got this new t-shirt that's come out two weeks ago called – not even two weeks – called not dead yet and they love it. It's like a punk statement. So in a way, I think sticking to the message of being a little bit punk about this might work. But if I was a millionaire, I could tell you it worked.

Researcher: That kind of Malcolm McClaren, Vivienne Westwood idea is…

Karst: Yes, yes I know, I love him. I actually met him when I was a child. He was so cool.

Researcher – Oh wow, fantastic.

Karst: Everything that comes with a bit of, kind of humour, and a little bit of lightness, we do. But um yeah, yes so that's that.

Researcher: And I suppose that ties in to what you were saying from the outset about making it cool and having a kind of really playful quality to it. It's to… I guess to perhaps take away some of this negativity around ageing and actually – you know – being fun and playful is OK as you get older. I think that's really lovely.

Karst: Yes. I think I perceive it as… For example, you know you have to wait until you're eighteen to get into a club – a night club – and it's really something that you look forward to? And I think when

you're a teenager you always want to be older. So my idea is that I have a club and you can only enter once you're… well I say sixty but obviously it's way too young for me, but I think from sixty to seventy you can get into my club… our club, and it's cool, and it's really something you look forward to. In a way, that's what I try.

Researcher: That's a nice idea. But actually, what I was thinking… I think what I was going to say before when I forgot my train of thought, was actually in many ways what you describe here sounds like an inclusive design approach, rather than necessarily just for a kind of exclusive club. Because there's a sense that it isn't… I suppose it comes back to that complexity that you were talking about. It's how do you pitch something for older… especially for older women, without telling them that this is for older women, so that they're not turned off by the fact it's for older women… if you see what I mean!

Karst: Ah, it's so, so complicated. But for the t-shirts, it's so obvious that it's for old people, but then I do made-to-measure. Now the made-to-measure is obviously… I could wear it. I sometimes wear my jackets and dresses and I think the ladies are very different. The ladies who come to see me, they come to see me for the skills, and the… because I trained in Saville Row so I know how to do fittings. I know how to make a garment flattering, and I specialise in prints, so they love the prints, and not a lot of designers do these big digital prints. So when I think this chunk of the ladies come, they come because they want a special dress, for a special occasion, and in that case, it comes to that. So, it's two sides of the work, but then I take the made-to-measure very seriously because a lot of things come up with the body and then I can address them with the lady – you know – her figuration and the measurements, and that's a completely different design approach. So, on one way we do the t-shirts, which is the message, the language and the concepts, and it's very pop, and it's very… it's really for everyone. And then the made-to-measure is really specialising, I think, for the ladies, but I have a lot of younger old ladies… well, I call them, you know; age of sixty, who just work and… yeah, so things like that. But – you know – for example, for design, something that is very important is that all the older women want sleeves so I always put sleeves; I don't do sleeveless things. And I think a lot of designers who do high fashion do sleeveless dresses. So I've had a number of ladies coming to me to say, "I just want a dress with sleeves". Or they will say, "I just want the right length", because they want to cover their knees or something. So I address these problems separately… which are not problems, sorry, these – you know – design details.

Researcher: Yeah, of course, yeah. And I think that's really important to kind of press that point that it's not problems. It's about meeting the expectations of the 'user', for want of a better term…

Karst: No, for sure, and I think, for example… wait, what was I going to say. No, I think, in general, that's where the message and the technicality meet. The ladies who I make dresses for (the silk dresses), they don't want something because it's designed for an old lady, because it's medical or something. They want something to look good at the party and it has to be… so it has to be: elegant, flattering, practical and comfortable. Those are my words. So, something that you can really move in that dresses you in a flattering way (and to flatter you can put little shoulder pads and – you know – incline the print in a certain way), and it has to be comfortable in the way that you can sit on it, or… lots of little details, so that's that.

Researcher: OK, yeah that's great.

Karst: But they don't want to come for medical clothes.

Researcher: They do? [misheard]

Karst: No, they don't

Researcher: They don't, they don't. Right, I was going to say.

Karst: Although I love medical clothes.

Researcher: What do you term as medical clothes? Like…?

Karst: Like hospital gear.

Researcher: Oh OK. Right, yeah.

Karst: Now the thing in the middle, between the t-shirts and the made-to-measure, that I have tried to develop, and it wasn't a success, because I tried to launch in France. But I wanted to do sportswear for ladies who don't exercise. So it was practical things to run around in the street or travel, like a lot… all the old… generation, they travel like crazy, you know? They're on the plane, they're on the train, they're on the bus, or they're walking around. So I really wanted to design clothes that you can really move in. So, if the idea… the illusion of energy and sportswear… because sportswear is cool, you know. Sportswear represents youth and activity. So I wanted to do that for old ladies, but a bit chic…

Researcher: That's nice…

Karst: And practical, you know. Like you could… there would be pockets where you could put your money or your jewellery, like I was thinking about all these very practical things for everyday life.

Researcher: Right.

Karst: But it's very, very difficult.

Researcher: Why do you think… what do you think the barriers were then? Why do you think that wasn't successful?

Karst: Well, I think money. I think I would need a huge investment of money to do that. Also I think, for me, I think it was a little bit too soon, like it was in 2012 and sportswear in Europe hadn't boomed yet, and certainly not in France. I think now, and living in America, everyone wears leisurewear or sportswear, or these kind of loungewear, you know. And I think that's perfect for old people because they're warm and they're all about technology, and I think it's really very, very good for the older peoples' bodies. Because it's comfortable and it stretches. I think that there's a huge, huge market for sportswear for older people, and I think now, the only people who do it – and they were really clever – but I think Uniqlo is like old peoples' heaven. Because they do these little puffer jackets that are very comfortable and thin, they do like thermal t-shirts. Uniqlo has mastered clothes for older people.

Researcher: Yeah, that's really interesting. Yeah, yeah… I think that point about the comfort and flexibility… I mean, that sort of ties in… and you picked up a little on it before about, kind of… body size and shape changing as we age. And you were talking earlier about specific tailoring considerations such as sleeves and, sort of, getting the dress length right. Are there any other, kind of, observations that you have in terms of ageing bodies and what that means in terms of tailoring?

Karst: Yes, yes. So I am very interested in that. The difficulty with ageing is that we all… the bodies change very differently, so in tailoring we call it figuration. So, for example, you might have a shoulder that's higher than the other. I think older people tend to have a more hunched back, so technically for design we give more fabric at the back, so it doesn't pull. And then shrink it at the front so… You know, it's all figuration and bumps and sizes, and the body changes very differently, so we address that. The problem is, that it makes it very difficult to do ready-to-wear because the bodies are so different, it's just, kind of, a whole new sizing thing and it changes for every single person. So my idea, if I could give advice to older people wearing clothes, is to wear sportswear, like to wear stretches trousers or, kind of leggings, very sportswear, and maybe, like, accessorise with chic… things, like a little silk jacket or a silk blouse, but technically it's a little bit difficult. That's why I do made-to-measure because then every case is different. But I've learnt that, yeah… it's difficult to know exactly how to size and to make clothes for old people. Other design things – you know – like little shoulder pads, I think always help, not those big eighties ones but little subtle ones. The length of the fabric is important. The length of the sleeves. I always like to show a little bit of the wrist because I think it's a beautiful part of peoples' hands, in general, so we show a little bit of wrist. I do

high pockets to have a better posture, and I do a lot of pockets because the ladies love it (and I do too, I think pockets are important). Just little details like that, you know. I, in dreams, I think older people will soon not be carrying handbags anymore because they're impractical and something like that. So you will have something like a little high bag or pocket where you can put your phone and your – you know – your wallet or, you know, travel light.

Researcher: Yeah, yeah, absolutely. No, that's… that, kind of, idea as well of perhaps combining the, sort of, ready-to-wear, sportswear stuff, which has that forgiveness and flexibility, and then maybe embellishing that with details which are perhaps a little bit more specialised, or bespoke, or personalised, I suppose. That seems to make a lot of sense. Yeah, absolutely.

Karst: Yeah…

Researcher: Very interesting.

Karst: I mean I say all these things but it's the dream for me. I would love to launch a small sportswear collection and I know exactly how it would look like. It would be very futuristic and cool and energetic, but the truth is, it needs a lot of investment at the beginning so it's always struggling with that, so yeah.

Researcher: Yeah, well, yeah I can see the appeal and actually, I guess also in many ways the work that you do – especially around the, kind of, printed t-shirts – it kind of starts to… you know, a t-shirt itself, it sort of sits within that, kind of, cross-over between casualwear and sportswear, doesn't it. It's kind of in that space between the two.

Karst: Yes, yes, I mean you'd be surprised about… to know how much people love t-shirts. I mean… yeah. And we do long-sleeves or three-quarter sleeve, but people buy t-shirts like crazy, for sure. I mean I would like to develop a little bit more and have more products but t-shirts work and – you know – the ladies, like, when there're hauts-de-seine couture, and I think there's comfortable – you know – also older people like things that wash easily, so that's something we think about. So yeah, I mean, there's all these – you know – things that… but I think really if anyone is doing it well – and subtly because it's for everyone – but I think Uniqlo, these days, corresponds to the ideal... I mean it's not very cool or perfect, but I think it's kind of the ideal – you know – example for older people to wear.

Researcher: Yeah, ok, ok. There's a couple more questions that I wanted to ask which I think you… I mean, inevitably when the conversation starts flowing these things perhaps get picked up a little bit anyway but… So what I wanted to ask was: what are the key challenges to designing for older people? And I suppose within that then… I mean you talked about some of the challenges in terms of

designing… the fact that ageing bodies all age and change shape, kind of, differently. Are there any other kind of challenges which perhaps aren't necessarily to do with the tailoring, but any other challenges that you find designing for older people?

Karst: Actually, I find all the challenges very exciting and I love resolving problems, thinking about…you know, thinking about the weather, thinking about the kind of life they have. You know, if they're still active or even if they need to be sitting down. You know, resolving technical problems that are to do with their life. Not the fact that they're old but the way they live their life. So, for example, if they can't stand or things like that. So it's resolving like that and things like that to make life very comfortable and to always have a sense of elegance – you know – even if you're lying down in the bed you should be a little bit elegant. I think the biggest challenge is to get over the taboo of ageing and of death and to try to find ways to… and also I think it's not just for the old people themselves but it's for all the generations to respect ageing more and to try and find a modern solution. I think trying to be modern and actually futuristic is a key thing for any design.

Researcher: OK, yeah, yeah. And I think perhaps in terms of that kind of idea of futuristic, I suppose the technologies that we may be using a designers in order to facilitate what… not just what older people are wearing but what everyone is wearing. You know, I'm thinking about perhaps the opportunities for made-to-measure using, kind of, digital scanning techniques and 3D printing, and sort of working in that sort of space I think is very, very interesting as well. And perhaps that… well certainly for my research that might be an area that I look at. I saw the… I was in London this weekend for the design festival and went to a pop-up that Adidas were doing where they were showcasing their 3D printed trainers, for example, and they use an algorithm to create a bespoke, sort of, trainer sole which, kind of, responds to the person's height and weight and their walking gait, and all this stuff is absolutely fascinating.

Karst: Yeah it's fascinating and I think we should not… I mean technology is going very quickly and all these new fibres and all these new things are going… it's going very quickly, the mixture of sportswear and technology. I find it absolutely fascinating and you always have to try and keep up with how fast things are going but certainly not leave old people behind. And I think there's still a problem with people who are trying to develop medical wear, you know, things that really address one problem in particular or… for example, I have a friend of my mother who had eye cancer this summer, and she brought me her eye patch and she says, "I can't wear it because it's just too… it's depressing. Can you work on making me like a nice, couture, chic eye patch?". So, I'm on to that. So, I think there's a lot of problems with people entering things medically that are very difficult and depressing, and I think if you're wearing nice things, or if you have a nice scarf, or a nice eye patch, or

a nice, kind of, medical blouse, it will certainly help for the morale, you know. So there's a lot of work to be done for designers and medical, kind of, supply people, to work together, I think.

Researcher: Yeah, yeah. I think… I mean that's very interesting as well. I mean, I think that, kind of, idea about what we might call clinical, sort of, scripted clothing, there's all sorts of things around power hierarchy and, you know, in terms of carer or doctor or patient, and the way that – you know – when you put on a hospital gown, for example, you're taking away, in many ways, your identity, aren't you, and your…

Karst: Yes, I think for some people it's very difficult. I personally love hospital wear. I love the big blouse, I think it's really cool, I always want to bring it home. I love what the doctors are wearing and things like that, but it's true that if it's too medical, or if it smells strange, it's going to be very, very depressing, and not everyone likes to feel so vulnerable. So I think it would be important to make sure that you keep strength and, kind of, honour no matter what you do or how bad your operation is, or your thing.

Researcher: Yeah, yeah, OK…

Karst: It's all about keeping honour, I think and… I don't know how to say it in English. A sense of…

Researcher: Yeah, your self-respect and dignity isn't it, I think?

Karst: Dignity, exactly. The word is dignity. I'm sorry, yes, dignity. Because you know like, the real sadness of it, and I've seen it for my grandparents and other people around me, is that when you grow old sometimes you're treated like a child and a baby in hospitals and things like that. That's a very, very difficult thing for me to imagine that you have to – you know – you have to wear the diapers, if you do, and things like that. That is certainly something that is very difficult and very taboo and I don't have a solution for it but… yes, that's really towards the end, but that's very difficult. But I think, every day, by changing the way we view age, and things like that. If we de-dramatize it we can certainly help every day and see with a bit of humour, and do tiny little things to make it a little bit nicer.

Researcher: Yeah, yeah, and actually what you just described there really – I think – ties in with that… with what was my final question there, is about the relationship between dress and those inevitable aspects of ageing. You know, as we get older… we may have reduced mobility; we may suffer from incontinence; those are all very debilitating things, and I think that word 'dignity' is so important, isn't it. That we can design clothing and apparel that, kind of, helps to maintain that dignity even when we do begin to – you know – lose our mobility or suffer from arthritis or osteoporosis, or…

Karst: No, of course, and what's important with that is that I remember my cousins never wanting to go and see my grandmother at the hospital because they found it depressing. I thought the hospital was great, the old peoples' home – you know – at the very end. But what was admirable is that the nurses would dress my grandmother every day. So she would be wearing a nice nightgown, but then in the morning they would dress her. And she was very skinny and very fragile so it took a bit of time to get her dressed because also she couldn't walk anymore. But they asked my mother to give her more like sportswear clothes, so she actually looked like a fun teenager in the end, which was fun. But they always brushed her hair and gave her a necklace (which is something she would've never worn. She was not a very feminine person). She was like sportswear and necklace and, like, brushed hair. She kind of looked really cool but it's important also, when you're an old person, to keep your dignity also towards your family because you don't want to show your children and your grandchildren that they need to take care of you. So if you look very dignified and cool, they will want to visit you and you're still the strongest person in the family.

Researcher: Yes, yeah, yeah. No that's… I think that's a nice thing to end on actually. That's I think…

Karst: Yes, it's like, "don't mess with us!". You know, like the old people, they all wear crowns saying, "I'm still on the throne, you know". Yes.

Researcher: That's wonderful! Fanny, thanks ever so much for talking to me…

Karst: Oh, cool, cool, it's been a pleasure. It's good to talk about these things also. It brings my mind back to what I'm supposed to do which I'm absolutely not doing these days. In dreams I will, so. Hey listen, good luck with your project. I'm very interested in the hip product. I would love to know when you make it and maybe one day I could sell it on my website, or something like that. I love, like, cool hip or cool accessories like that. I think it's got a lot of potential.

8.7 Appendix G - Transcripts of focus groups with active older people

Female focus group. Recorded 8th February 2019.

Researcher: Would you consider wearing a HP (either worn under or over clothing) and in what circumstances?

Participant 4: I would definitely wear one if it was necessary, or… I mean, at the moment I don't feel like it is, for my hips, but I would definitely know when to use it for my own safety, and for pain relief and that. But looking at those two, at the moment, I would prefer that one…

Participant 2: The black one [HiP]. This is hard [points to Fall Safe pad]. Very un-resilient (sic).

Participant 3: Apart from being hard, it looks awful.

Participant 2: Yes, even if it was black. That [HiP] looks more business like.

Participant 3: And it looks as if it's pockets with a lot of money in them. You'd get away with saying it's a mobile phone, you'll be lobbed on the head!

Participant 1: With a woman, that's our widest part. Would they ride up? Just a thought.

Researcher: Well, yeah, that's certainly something to consider.

Participant 2: Have you seen on Facebook, three times this week, they've shown an advertisement with an elderly lady and a very old man falling. And this elderly lady walked out in front of the camera, with a stick, and she went down like a pack of cards. And they had a garment on which inflated and it was sensitive to the movement of falling. And so they went down, splat, like that, and the woman actually bounced on this garment. And I thought if that's on the market. And as they were walking you were unaware of any thickness here, or any additional clothing and I thought, has your job been done?

Researcher: I wasn't going to talk about inflatable ones today, but I'm obviously very aware of that technology. Is everyone aware of the inflatable…?

All: No

Participant 4: [Participant 2] told me about it.

Researcher: So [Participant 2]'s got the knowledge from Facebook. OK, well perhaps if we were thinking about the three styles, not just these two but something which was a belt. So, effectively the inflatable ones that [Participant 2]'s talking about are…it's a belt where the actual…it's much more low profile and it has sensors. So it's battery charged, so you have to charge it up. It has sensors in it that can detect…it can tell the difference between walking - and getting up and sitting down – and falling, and in the event of a fall, airbags, like in a car, jettison around your hip…

Participant 3: Ah, they're not out all the time?

Researcher: No, so it's a technology lead product.

Participant 3: Not like the bubble wrap man walking down the street!

Researcher: No… So perhaps if we were thinking about the circumstances where you might wear one of three of those things, would you feel comfortable wearing one of those?

Participant 2: The trouble is, you can't anticipate when you're going to fall. I had two falls in one week which I never had before, and I haven't had since. But silly things: making the bed, the end of the duvet stuck out, I caught my foot in it. And the same thing, I put my foot up on a chair to do my shoe up, which my husband always does for me, and I just overbalanced and went flying. You can't anticipate that, so if you're going to anticipate when to wear a garment, how would you work that out?

Participant 3: I think that sort of blow up garment would be very good if you were going out, down the beach, walking in the country or a long walk, or going into town perhaps? I don't know…

Participant 2: The cobbles!

Researcher: So are you suggesting then it's perhaps something you would actively wear just in certain circumstances?

Participant 3: I would think that. I don't think that it's… It's not every day wear.

Participant 2: No

Participant 3: I mean I can't imagine wearing anything with thick padding every day. I mean, 'cause I've had a few falls and what I've broken has got nothing to do with hips. It's everything else that's broken falling down.

Participant 4: You see, I haven't fallen but I've got this terrible fear of falling.

Participant 2: I think that's universal.

Participant 4: And this is what's holding me back walking. Because there's no reason, I don't think, no reason that I can't walk properly. You know, I've just got this fear. But I've not only just had that since I've had the stroke, I've had that even since I was a young woman…

Participant 2: Oh really?

Participant 4: Like skiing and that. I've always had a fear of falling.

Participant 2: I think Marina, who will be here another time, I think she's exactly the same. Terrified of falls.

Participant 4: It's awful but it's here and I've just got to get it out of my head.

Participant 1: I used to fall all the time as a child because…

Participant 3: My knees are marked still.

Participant 1: Because instead of my feet going like that [points outwards] I walk like that [points inwards], plus…

Participant 2: Pigeon toed.

Participant 3: That's it

Participant 1: Yes, so I don't have the fear. I'm sitting with this on now [wearing the HiP product over her trousers], and actually, to be honest, it's quite comfortable.

Participant 3: Yes, it looks quite comfortable.

Participant 1: I would never, ever wear that [points to Fall Safe product]. It's too hard…

Participant 3: I think that would move as well.

Participant 1: It doesn't even feel hygienic. I don't want to wear them.

Participant 2: And it looks masculine. I mean that's the shorts. They look like men's pants. And totally off putting. It's so hard [the Fall Safe pad].

Participant 1: Well, they can change the… it is very hard.

Participant 4: It's like I said to you last time. Thinking about when my mother had them. Now that's a long time ago and they were horrendous things. You know, big pants down here [points to knees] and great things here [points to hips], and everything, and she took one look at them – she was a bit like me really – and she said, "no way am I wearing those. No way". So she took the risk of falling which she didn't do.

Participant 1: See I would wear this.

Participant 2: How much protection do you get from that?

Participant 1: It can move, they're quite good. They're not heavy…

Participant 3: Yeah that's one thing when I looked at it, it wasn't heavy.

Participant 1: They're not heavy at all. You don't really know you've got them on.

Participant 3: I wouldn't like it if it was attached to Lycra pants, 'cause trying to get on Lycra, with padding in, is a nightmare.

Participant 2: It would be.

Participant 3: Oh, absolute nightmare.

Participant 1: I don't really wear Lycra.

Participant 3: The thought of pulling it up, say they were shorts made of Lycra. When you try to pull things up – I mean, I went through months of not being able to use my arms. I couldn't even pull on my knickers, and they're not made of anything except nylon!

Participant 1: That's the other thing I was going to say. Being ladies, you know, we don't want to struggle to get something down, we want something that can really stay in place, and then the pants can go over the top.

Participant 5: That's [HiP] alright for the garden.

Researcher: The garden? OK.

Participant 2: That doesn't look like it's got much resilience against someone who is heavy, like me, going down onto that. Would that protect my hip?

Participant 3: Would it be designed individually for people or is it just a size 12 to say 6?

Participant 1: It couldn't be, because it needs to be in the right place.

Researcher: Absolutely, I mean these are available in, I think, four different sizes, and you obviously choose a size in relation to your body size. And I think there is some information actually on the garment itself about positioning. So, because you're absolutely right. There's no point wearing it at all if it's not protecting the bit it's supposed to be protecting.

Participant 2: To me, it should be a little bit longer. Looking at Participant 4's hip there as she was sitting.

Researcher: Do you think it has a tendency to ride up…

Participant 4: It will do.

Researcher: …when you sit down?

Participant 1: I've worn a lot of support garments and a lot of them would just ride up. As a child, they ride… So the belt that I've got now has rubber at the top and at the bottom. They still ride to a certain level but you do need to have something to keep it positioned. Men are a different shape, and us girls, you know. Like me, I'm not level.

Participant 2: Some people have got saddle bags quite low haven't they? Would you wear that against your skin then put your clothing over the top?

Participant 1: Yes, I would, because I'd want my knickers so I could take them down.

Participant 2: So that rubbery stuff would cling to your skin.

Participant 1: It does. I've got one on right now. I could've brought one to show you.

Researcher: There's a silicon band, isn't there, on the inside of that belt which has a kind of grippy…

Participant 3: It looks as if it's gripped.

Participant 1: Yeah, it's not very big that silicon, it's only…

Researcher: There's two bands.

Participant 1: Oh there's two? Right. When I come again, I'll show you…

Participant 2: I think that would stick to your skin if you haven't got talcum powder on, or anything like that.

Participant 1: I don't use talcum powder. It's not very sticky. It's not as sticky as the one I wear.

Researcher: So would you perceive that as something you would wear under your clothes as opposed to over your clothes?

Participant 1: Yeah, definitely.

Participant 4: Yes, definitely.

Participant 2: Absolutely.

Researcher: Yeah? Is that the general consensus?

Participant 3: It makes you feel a little bit… If you've got trousers on I think that'll be alright. Nobody would detect it, especially if they were black trousers. They would just think they were extra pockets on one of these funny bags that people wear to go on their bicycles or whatever.

Participant 2: I don't think that [HiPS] would show up much, because we've all got room on the outside of our trousers. But I wouldn't want to actively put that on just because I happened to be going into town and trip over a cobble.

Participant 3: And you can trip over them… [indistinguishable due to background noise]

Participant 4: Yeah.

Participant 1: I think you've got to wear it all day and it's the same with [sic] I wear a support belt. I get up, I have my shower, and then I put the support belt on. Then I go to bed and I take it off.

Participant 3: I think it would have to be that.

Participant 1: And even when I'm abroad and I didn't realise it was going to be so hot, I still wore it in 34 degrees, because you have…

Participant 2: It's a protection for your mind…

Participant 1: Well you have to make a choice. Do you want a broken hip or do you want to at least think that this is going to save you? It's the same with me; I've got a hernia, I can't have surgery to have it repaired, so I don't want it to get any worse. So, it's a choice you have to make.

Participant 4: Yeah.

Participant 1: Do you want to help yourself or do you think, well actually I don't mind? It's like coming here for our benefit…

Participant 2: I think it's a mental thing far more than a physical thing.

Researcher: Yeah.

Participant 3: Some people will say, that's lovely, I'll wear that no trouble, even the pants. It's personal.

Participant 1: You can get support pants. I tried those and did use those for years, but then you've got to take them up and down, and also you've got that extra thickness. You don't want something that's too thick and you want something that's light and cool for the summer.

Participant 3: I think that's [HiPS] a lot better than I've seen.

Participant 4: You see I've got no experience of wearing anything, any support. I just wear ordinary knickers. You know, because I've just got no experience of any of them.

Researcher: But you were talking earlier about a fear of falling, so Participant 2's point about this helping psychologically, would you feel that something like that [HiPS] would give you more confidence?

Participant 4: I don't know really…umm… I think really I'd have to see, wouldn't I. Because… well it's not so much… Although, you know, I was nursing, I've nursed on orthopaedic for years and hips and all the rest of it, but it's not the fear of my hip going if I fall, it's just the whole thing of falling. It's not worrying – which seems ridiculous – it's not the one thing that I'm bothering about is my hip going.

Participant 2: No it's everything.

Researcher: OK.

Participant 4: It's everything…

Participant 2: It's shoulder protection, elbow protection, hip and knee protection, you need everything.

[Background] It's just one I happen to [falling motion and slaps the table], and put my hand out. You need a wrist protector.

Participant 4: You see I think what put me off, which unfortunately happened here, and it was… I think must have been about three years ago because we've not done it since, but going from chair to floor.

Researcher: OK.

Participant 4: Now, I was walking well with a stick, going over the different things they had to step over and all that, and doing all that, and getting off the chair – we were in the other big room then when it happened – got off the floor, no problem, walked down to get down, and I didn't do it right. I should've brought this leg round and I didn't, and the whole weight went on this leg…

Researcher: Oh, I see.

Participant 4: And of course I had to go and have scans on my ankle and all the rest of it. And then it transferred… the pain transferred from this foot to this one, because I was putting all the weight on it. I mean it's a long story and, you know… So, I think that put me off because if it's suggested now, going from… which we should be doing, you know. I quite agree we should be doing it, or I should be doing it. I would say it's a definite 'no no', because it's in my mind that that happened, and the fear of it and the pain of my feet is into my head now. They know, Helen and Pat know, and I have Pat come to my house and everything, and they're trying to get that out of my head but there's only me that can do it.

Participant 2: I think there's another fear as well. I've had three shoulder replacements and one hip joint replacement and I've been told that if I have a fall and break that hip they can't do anything more for it. Because I've got so much arthritis, the bones are just crumbling and my spine is crumbling. So, I think I would need an all-round cage…

Participant 3: …a big bubble [indistinguishable], like Michelin Man.

Participant 2: Yes, I just feel that one little pad will give me a bit of confidence but not the full whack.

Researcher: Yeah, OK, that's interesting. So if we were thinking about, with these two products which I'm showing you, the advantages and disadvantages, just to bring the conversation back round to…

Participant 2: Too hard [Fall Safe], more attractive [HiPS].

Researcher: OK. Is that the sort of general consensus?

Participant 3: Yes, I think…

Participant 1: I don't think any of us would wear that [Fall Safe]…

Participant 2: No

Participant 1: Also it might slip around a bit. You've got to have something that's going to sit firm round you.

Participant 2: I wonder how much resilience…? Has that [HiPS] been tested?

Researcher: Oh yes. This is a product from a Norwegian company called Protex.

Participant 2: I'm just wondering what the amount of weight going onto it, how much protection there is there?

Researcher: Yeah, the impact resistance of the pads, yeah…

Participant 3: It's very difficult to know from one person to the other how they fall.

Participant 4: You see, if that was me, I would wear something like that [Fall Safe] but it would have to be feminine…

Participant 3: Oh yeah, a different shape or fabrics.

Participant 4: You know, I wouldn't put those [Fall Safe] on…

Participant 2: If it's slippery as well, you'll get it on better. Better than cotton.

Participant 4: …it would have to be feminine for me.

Researcher: OK.

Participant 4: I know that sounds a bit stupid…

Researcher: No, no, that's fine, that's absolutely fine.

Participant 2: No, no that's [Fall Safe] so ugly. I mean when you showed them the first time, the whole group laughed.

Researcher: Yeah.

Participant 1: Don't like that [Fall Safe], I would wear that [HiPS].

Participant 3: That's right, I would wear that [HiPS].

Participant 2: That [HiPS] looks business like.

Participant 4: It would be interesting really to know, if my husband came in, what he thought of those.

Researcher: Well, I'm going to do a session with the boys as well…

Participant 1: They're [Fall Safe] just too heavy and uncomfortable and they may not stay in the right place.

Participant 2: I think they're [Fall Safe] too hard. They're uncomfortable.

Researcher: So this actually leads quite nicely into the next little bit that we'll do. Interestingly, this type of product [Fall Safe] – the underwear type of product – is much, much more widely available than this [HiPS] sort of product. There are fewer manufacturers making this [HiPS] sort of product…

Participant 2: How much are they?

Participant 3: Probably expensive…

Researcher: OK, I'm not going to tell you at the moment because I wanted to get your perspective on things.

Participant 3: Save that for later!

Participant 2: If it's Norwegian, probably quite pricey.

Researcher: What I'd like to do is a little exercise with some cards here. There're ten different examples of hip protectors which are available on the market, and what I'd really like is if the five of you could put these in order of most appealing to least appealing…

Participant 3: What's acceptable?

Researcher: Yes, most acceptable to least acceptable. And really I suppose what I'm most interested in is the discussion that you're having together to determine that.

Participant 2: There're those… That's, again, the same sort of thing. And that's the one Participant 1's got isn't it?

Participant 3: Yes…

Participant 1: No, that's not my one…

Participant 2: No, no, actually that's one you have to put on, don't you, like pants.

Participant 3: I don't know…

Participant 1: No, I think you'll probably be able to…

Participant 3: This one's like a girdle…

Participant 2: But that's got no gusset.

Participant 3: No, but there again you could go to the toilet in that one, as a female.

Participant 2: Ish, ish!

Participant 1: You could, but it wouldn't sit right. That's why I think… because I wear support garments, that's why I'm here. I'm a bit young for all of it but I know what's… what people wear.

Participant 2: That's a longer garment. So these look similar, don't they?

Researcher: They are very similar but they're different manufacturers. And this is just a small selection of…

Participant 2: That looks very. I think that ought to come right down here because it's spongy.

Participant 3: It's horrible.

Participant 2: People would wonder what was wrong with you feeling that. [laughter]

Participant 3: Excuse me, you're not going to feel me! Stand in the bus queue!

Participant 1: I think that's awful.

Participant 3: That's dreadful.

Participant 2: Awful, that's down there. That's similar to those isn't it? Again, that's got…

Participant 3: That's nicely shaped but you've got to pull it up and down.

Participant 2: That doesn't look as if it'll protect very much does it?

Participant 1: That's like… Oh it has got… It is pants.

Participant 3: It is pants. The only one that is not a pant between those is that, or that.

Participant 2: But that hasn't got a belt. They're all pull-on.

Participant 3: Are they pull-on or is that hooked or something.

Participant 2: Or is it velcroed?

Participant 3: That's what I'm wondering.

Participant 2: Is that velcroed?

Researcher: That is a Velcro… oh, let me just check…

Participant 3: Does it open on the side?

Researcher: I think it does. Yeah, it's a wrap around, that one.

Participant 3: Ah, that makes a difference. That's not too bad.

Participant 2: Ah, so that's better. At the top?

Participant 1: Yes, I think.

Participant 2: Sorry, I don't want to be bossy here!

Participant 1: You're not! What about that one?

Participant 3: That's a pull-on.

Participant 2: That's slightly better than the pants aren't they.

Participant 3, Yeah, because we don't like the pants.

Participant 2: So that goes next, does it? Would you say that?

Participant 1: Yeah.

Participant 3: Yeah.

Participant 2: What do you think, [Participant 4]?

Participant 3: If you had to wear one?

Participant 2: Those two are both horrid. Those three are horrid.

Participant 1: That's quite bulky though if you look at it. I looks quite deep, doesn't it.

Participant 3: Yes, quite deep. It depends on what sort of break you're going to have.

Participant 2: But don't you think they ought to be thicker for more resilience, to do the job?

Participant 4: Oh yes, yes.

Participant 1: No, not necessarily.

Participant 2: I mean if you've got foam, it just gives.

Participant 4: No, I think definitely.

Participant 3: …[indistinguishable] where his or her hips are. That looks very low.

Participant 4: That, under the clothes. You wouldn't notice it.

Participant 1: I don't know because we do in those ones.

Participant 2: That's allowing for more difference in figures isn't it.

Participant 1: I don't like those because you slip them in and I don't think they're in the right place, and they're not wide enough.

Participant 2: I think these are universally awful.

Researcher: So those are all joined, the worse.

Participant 2: And those really are like that.

Researcher: OK, alright.

Participant 2: And then those two at the top. OK, happy with that? Is everybody happy? Sorry, I must go…

[Participant 2 leaves the group at this point].

Participant 1: I could bring in the belts that I wear, so I've got one that is velcroed.

Researcher: Oh I would be interested to see, yeah, thank you.

Participant 1: They're the same price, the different belts. And I could even show you the pull-up pants but I don't like those anymore.

Participant 3: No, no, I don't…

Participant 1: Especially for a hernia because once I put it on, I want it to stay on.

Participant 3: And you're taking it down to go to the loo, yeah…

Participant 1: No, I don't want to take it up and down. I'm really sorry I can't stay longer […]

[Participant 1 leaves the group at this point]

Researcher: So just to develop this a little bit further, I think there was a consensus about the visual appearance of these ones. This is what we're saying is the least attractive. Then we've got a middle tier here, and then these are the best options.

Participant 3: That's right.

Researcher: So what's the rationale for these two in particular?

Participant 3: Well it's the femininity of them. You can go to the toilet without taking them down or out or off. With all the rest of them you have to pull down and if you've got anything wrong with your arms – which a lot of people have that've got things wrong with their hips – then you're going to have a lot of trouble.

Researcher: OK, that's fair enough. In terms of what you would expect to pay for these, I wonder of you could now sort these in terms of your perception of what's the most expensive and what's the cheapest?

Participant 3: Well I think, the one that we selected that looks a bit like the black one you had, is the most expensive. I don't know, but just gather that it would be the most expensive. We're talking about at least £25 upwards.

Researcher: That's OK. Don't worry about what it actually… it's just about your perception. So, do we think that's probably the most expensive anyway?

Participant 3: Yes, there's more detail.

Researcher: Which do you think is probably the least expensive?

Participant 3: Something like this, which is very similar to that.

Researcher: Yeah, OK.

Participant 4: And that one.

Participant 3: Yeah, and that might be the least expensive as well.

Researcher: So do we feel it's kind of in the same order then?

Participant 3: I think price-wise we'd put it similar to liking.

Researcher: Yeah.

Participant 4: If I needed it and I really liked it – me personally, and I'm not speaking for anybody else – I wouldn't mind what it cost…

Participant 3: Oh no, that is something different, yes…

Participant 4: Because you're asking about prices and that. It wouldn't really bother me because I'd stop something else.

Participant 3: That's right, you would do without something else…

Participant 4: I'd stop Sky Sports, something like that. You know, for my husband.

Participant 3: I think that's how the ones with the gusset, to me, as a lady, would be spending money wastefully, you know. Whereas the ones without the gusset, you'd be willing to spend more just to get the convenience.

Researcher: OK.

Male focus group. Recorded 22nd February 2019.

Researcher: […] and that's a common idea about what a hip protector garment is.

Participant 2: Right.

Participant 1: It's not really a fashion garment is it?

Researcher: It's not. Well this one [Fall Safe], yeah that's an interesting observation, yeah, it's not. It's something that's worn under your clothes as well.

Participant 1: OK.

Researcher: This is another type of product, which is produced by a Norwegian company, which you wear over your clothes. So this is a belt, which goes over the top, and obviously, again, you've got the protection that comes round over your hip joints. My question to start off with – and by all means, do feel free to have a look at those and handle them if you'd like to.

Participant 1: Do they sell them now, ones outside the clothing? I've never seen anyone wear one of those.

Researcher: Yeah, it seems that this [Fall Safe] is a much more accepted product and is used more widely, and this [HiPS] because it's worn on the outside. So I suppose I'm interested in your views on… whether either of you would consider wearing something like this and ultimately, what appeals more; something that's worn under, and it's hidden – but accepting the fact that maybe it's something you have to wear as part of just getting dressed in the morning, and it fits into that process – or whether something like this…

Participant 2: Silly question, why can't I wear that under my trousers?

Researcher: You could, yeah.

Participant 1: What, the black one?

Participant 2: My question is, why can't I wear that under..?

Participant 1: You do?

Participant 2: Yeah, could do.

Participant 1: Oh, could do. Oh right, you don't wear them then?

Participant 2: No, it seems to me, cosmetically you might want to put it underneath your trousers.

Participant 1: Yes.

Participant 2: There's nothing to stop you doing that.

Researcher: That's absolutely right. Certainly the way that they market this, is it's something in all their photographs which they say […] which is worn over the top. But even in their literature they describe how you could wear it under your clothes if you wanted to.

Participant 2: Fair enough. Quite a lot thinner than that isn't it [referring to difference in pad thickness]?

Researcher: Well, that's certainly the perception, isn't it? The material that they use (which is the padding bit) is a non-Newtonian polymer which is flexible but on impact becomes much more rigid. So they certainly – if you believe what they say in their marketing literature – it does offer some form of protection.

Participant 2: Right.

Researcher: Yeah. Do you think what... if you were to wear something like this, in what circumstances? Is it something that you think that you'd wear just generally on a day-to-day basis or are there particular circumstances where you think you'd be more inclined to think about wearing a hip protector?

Participant 1: Personally, I have not fallen - touch wood - I don't need to wear a hip protector.

Participant 2: No, I haven't fallen over yet. I've got Parkinsons but haven't got to that stage yet.

Researcher: Okay.

Participant 1: But really it's a bit difficult to answer that question.

Researcher: No, no, that's a perfect answer. I mean, yeah.

Participant 1: I never thought about it, quite honestly, until a couple of weeks back. Which doesn't look strange to me? Perhaps that does? Or out the way. I really don't know.

Researcher: Okay. Okay.

Participant 1: I suppose you could wear that in the sun but as an outdoor garment. If you're at the beach if you're that way inclined.

Researcher: Yeah, you could.

Participant 1: More possibilities in a sense than that one.

Participant 2: This this one?

Participant 1: Yeah, the white one.

Researcher: Yeah.

Participant 1: The shorts.

Researcher: Yeah, yeah. So do you think... Are you suggesting then if we thought about those not necessarily as an undergarment, but actually just as a pair of normal shorts with something integrated into them? Well, the padding integrated into them.

Participant 1: Well, you could do I think you could. I think it would be more accepted in a sense in the summer time. I'm not likely to end up wearing shorts anyway [...] I don't wear shorts anymore.

Researcher: Okay.

Participant 1: Personally...

Researcher: Yeah.

Participant 1: How old are you going to be before you start getting your hip replaced? I haven't a clue.

Researcher: Well, it's not necessarily about if you've had a hip replacement...

Participant 1: Or protecting your hip...

Researcher: It's about protecting, yeah. So I think that's really around if you're more susceptible or someone at risk of falling, then obviously... It's one of these things, isn't it, like you don't know when or where...

Participant 2: That's right.

Participant 1: Yeah, yeah.

Researcher: So. But certainly in the studies that I've looked at, when a hip protector is worn, it does, offer more protection and there's about a 50 or 60% decrease risk of hip fracture if a hip protector is worn at the time of a fall. Okay...

Participant 1: Well it comes into that point of whether you're gonna wear that, just in case I fall. Fifty million dollar question...

Researcher: I suppose that was kind of what my question about like what circumstances do you think you're perhaps potentially more at fall risk.

Participant 1: But the older we get the more fragile you become, more you become, the more unsteady you become.

Participant 2: Yeah, yeah.

Participant 1: Can't say any more than that really.

Researcher: That's fine. Yeah, thank you.

Participant 2: Don't know if you remember a member of this group couple of weeks ago [...] He used to fall over ten times a day.

Participant 1: Really?

Participant 2: He had Parkinsons quite badly.

Researcher: Right, right.

Participant 2: So that may be an area to look at. There are several Parkinsons groups in the area who meet. Some to meet as well.

Researcher: Yeah. Yeah, that's helpful, actually. Thank you. Yes. Yeah. Okay. Okay. I don't want to take up too much more of your time. But if we could do just one last thing. So this is what I did with the... a similar thing with the... when I spoke to the female group a couple of weeks ago.

Participant 2: Yeah.

Researcher: So I've got some examples - other examples - which aren't these of different types of hip protectors. And what I've tried to do is, some of those are specifically male, some of them are unisex. So it's a bit of a mix. You can see the kind of, sort of different... different set of types. And really what I would like is just to know, if you were going to put these in order of... I guess, just looking at the picture, so it's just about the way these these appear. Which ones would you say are the most...

Participant 1: Appealing?

Researcher: Appealing. That's a good way of putting it, yeah. And just put them in order of, you know...

Participant 1: Choice.

Researcher: Yeah, absolutely. And if perhaps, you were able to have a discussion about ordering that, and referring to the numbers on the cards, then that would be very helpful.

Participant 1: I'd go for four.

Participant 2: Why is that?

Participant 1: Because it's a gents' garment for the start of it.

Participant 2: True.

Participant 1: That one there, the same reason.

Researcher: Yeah.

Participant 1: I know that's a gents'... Is that a gents' garment?

Researcher: Well, it's more of a...

Participant 1: Unisex...

Researcher: It is unisex. It's modelled on a female body but it is a unisex garment that, yes. Similarly with this one as well.

Participant 1: Yeah.

Participant 2: Thought it looked more perfect.

Participant 1: Yeah, definitely, yeah.

Researcher: And then this one is another one a little bit like this... there's

Participant 1: [indistinguishable]

Researcher: Potentially.

Participant 1: I think that's a deeper one, isn't it?

Researcher: Oh, yes, the pads.

Participant 1: Yeah, the padding.

Researcher: Thicker on that one...

Participant 1: Yeah.

Researcher: Than that, certainly.

Participant 1: Yeah.

Participant 2: Yes, I'd go for that I think.

Researcher: Okay, so that's number six. So do... So these, are these equal?

Participant 2: Yeah, probably. Yeah.

Researcher: Okay, so that's six four and three.

Participant 2: That's not got a lot of padding by the look of it, I don't know if that's true.

Researcher: It does look quite low profile maybe, yeah.

Participant 1: That would actually be much more appealing for a man to cater for a man's functions. To put it that way.

Researcher: Yeah, yeah.

Participant 1: I don't know what that one is.

Participant 2: What? This one?

Participant 1: Yeah, no idea. Okay, it's from a different angle. But...

Researcher: So that's number one. Yeah.

Participant 1: That's a ladies one anyway, I believe.

Researcher: Well...

Participant 1: Looks like it anyway.

Researcher: Okay, so that's number ten. Yeah.

Participant 1: And eight as well.

Researcher: Yeah, so they're both unisex but, yes, the pictures are modelled on women.

Participant 1: Yeah.

Researcher: But I suppose I guess the question is, you know, this is doing something a little bit different because it's not a whole garment it's kind of... just the pads so whether that would be appealing or not?

Participant 2: Yeah.

Participant 1: I mean, to my mind, the least fussy you have, the better

Researcher: Yeah.

Participant 2: Yes, but then when...

Participant 1: Easier to pull it off or get it off.

Participant 2: ...when you're falling over, in the process of falling you wish it was thicker.

Participant 1: Yeah, exactly. That's what you want.

Researcher: Maybe so... These are... I think you've kind of given some good reasons to why... what's this? Three, four and six feel the most appealing. Which ones are perhaps right at the bottom end, not appealing at all? You wouldn't want to go...

Participant 2: Well that looks very flimsy, I mean, it doesn't look as though it would...

Participant 1: Yeah, not much there. No substance in that one, is there.

Researcher: Yeah.

Participant 1: That one looks... it's a bit low.

Participant 2: Maybe.

Participant 1: Below your hip, isn't it, I think.

Participant 2: Don't know.

Participant 1: Don't know.

Researcher: Yeah.

Participant 1: That looks very bulky too.

Participant 2: I think if you feel you're in danger of falling you wear...

Participant 1: You don't care.

Participant 2: ...the most protection you can.

Participant 1: Yeah, you just don't care.

Participant 2: And if you feel that, well it's not going to happen to me, you're not worried.

Researcher: Yeah, okay. So there's... Do you think there's a kind of trade off between something that's going to be comfortable, but something that's going to be thick... thick enough padding...

Participant 1: Yeah.

Researcher: To do the job? Yeah.

Participant 1: Yes, definitely. Otherwise there's not much point in wearing it really is there?

Researcher: Well, quiet. Yeah. Okay. All right. Okay. Any other sort of final comments at all about any of the images?

Participant 1: Well that's male, unless it's a very hairy female. I think they are female. Looking at this... Looking at a curve, a curvaceous sort of thing.

Researcher: Yes, yeah, I mean, but the products are unisex. But yes, yeah, that's right.

Participant 1: I've no really particular strength, weaknesses, in any of these things, so.

Researcher: There's a lot of similarity in the way they look, yeah.

Participant 1: Yeah, indeed. You're protecting your hip, where whichever way it goes, isn't it.

Researcher: Okay.

Participant 1: So sorry, can't add any more.

Researcher: No. Okay.

Participant 1: Hope I don't have to wear one.

Researcher: Yes. Yeah. Well, thanks ever so much. I really appreciate your time.

Participant 2: It feels as though we've been inadequate for you.

Researcher: No...

Participant 2: Very basic.

Researcher: No, I think that's really helpful. I don't want it to take up more of your time. But it's... Yeah, great to meet you. Thank you very much. Thank you.

8.8 Appendix H - Online survey questions

About you

Firstly, let's find out about you and your perception of fall risk:

1. Do you describe yourself as a woman, a man, or in some other way?

- Woman
- Man
- _____

2. What is your age?

- 39 or under
- 40-49
- 50-59
- 60-69
- 70-79
- 80-89
- Age 90 or above

3. Have you ever been diagnosed with osteoporosis?

- Yes
- No
- Prefer not to say

4. Have you ever experienced a fractured hip?

- Yes
- No
- Prefer not to say

5. To what extent is the following statement true for you?

"I consider myself more at risk of an accidental fall now compared to earlier on in my adult life".

- Extremely true
- Somewhat true
- Slightly true

- Not true at all

6. Why do you feel that way? (Tick all that apply and please type in the 'Other' box any other reason).

- I feel more vulnerable because I have osteoporosis
- As I have become older I sometimes feel less stable when walking or standing
- I have other health conditions that affect my balance or mobility
- I have fallen before which has affected my confidence
- Other

7. Have you ever worn a hip protector garment?

- Yes
- No

8. Describe the appearance, comfort and ease-of-use of the hip protector you have used.

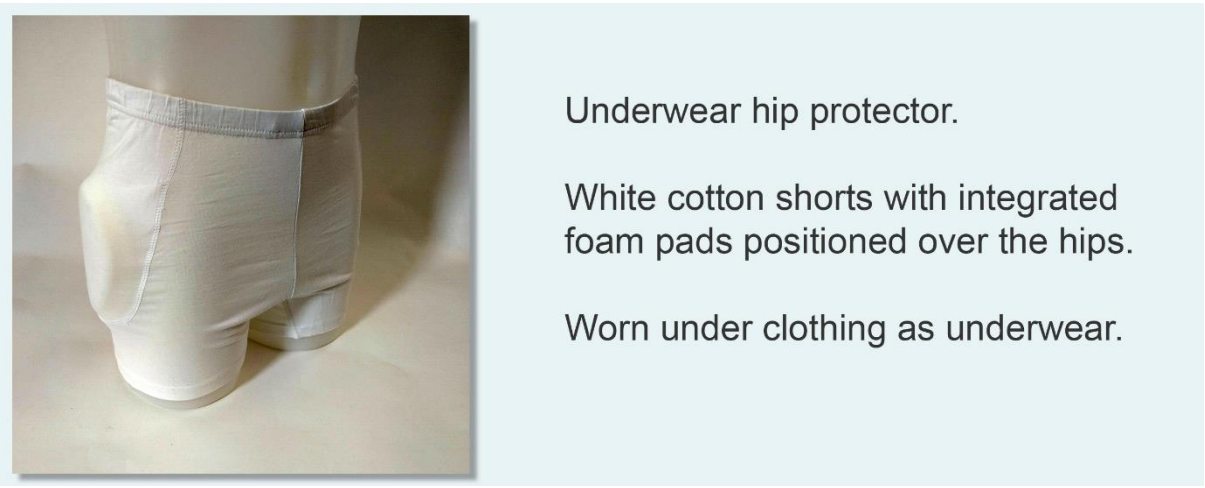
_____

Hip Protectors

The next few questions will explore your attitudes towards current types of hip protector garments. Examples of unisex hip protectors are shown:

9. Several manufacturers produce underwear hip protectors like the garment shown here.

If you currently feel at risk of falls, would you wear an underwear hip protector like this?



Alt text: Underwear hip protector. White cotton shorts with integrated foam pads positioned over the hips. Worn under clothing.

- Yes
- No
- Not applicable

10. How likely or unlikely is it that you would choose to wear an underwear hip protector at a time when you feel at greater risk of falling? *

- Very likely
- Somewhat likely
- Neither likely nor unlikely
- Somewhat unlikely
- Very unlikely

11. To what extent do you agree or disagree with the following statement?

"I like the appearance of the underwear hip protector example".

- Strongly agree
- Agree
- Neither agree or disagree
- Disagree
- Strongly disagree

12. What do you like about the appearance of the underwear hip protector? (List up to three features).

_____

13. What changes to the appearance of the underwear hip protector would make it more appealing to you? (List up to three changes).

_____

14. What three words do you feel best describe the appearance of the underwear hip protector? (Write the first words that come to mind).

1st word...

_____

15. 2nd word... *

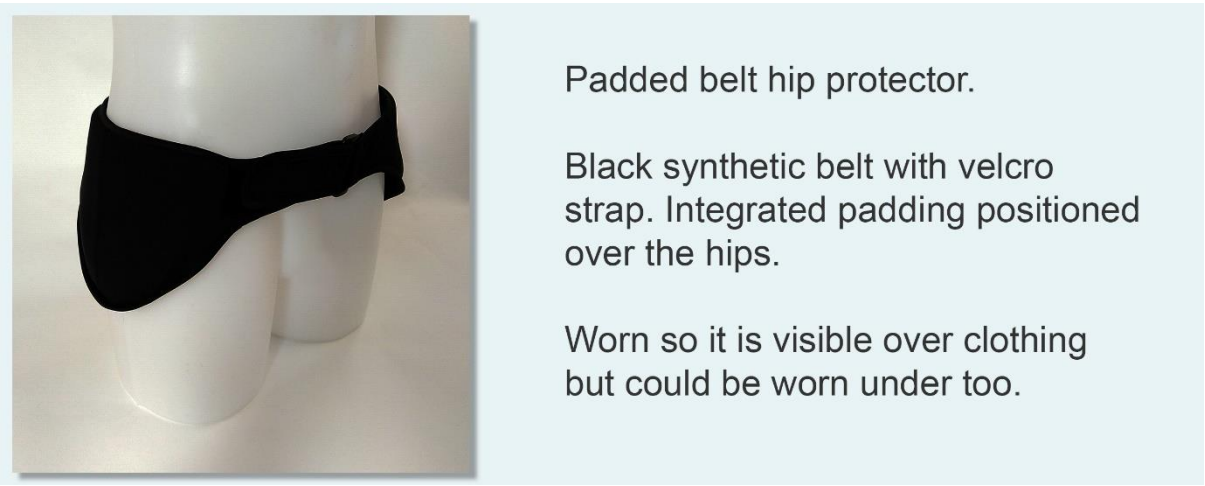
_____

16. 3rd word...

_____

17. Several manufacturers produce padded belt hip protectors like the garment shown here.

If you currently feel at risk of falls, would you wear a padded belt hip protector like this?



Alt text: Padded belt hip protector. Black synthetic belt with velcro strap. Worn visible over clothing but could be worn under too.

- Yes
- No
- Not applicable

18. How likely or unlikely is it that you would choose to wear a padded belt hip protector at a time when you feel at greater risk of falling?

- Very likely
- Somewhat likely
- Neither likely nor unlikely
- Somewhat unlikely
- Very unlikely

19. To what extent do you agree or disagree with the following statement?

"I like the appearance of the padded belt hip protector example".

- Strongly agree
- Agree

- Neither agree or disagree
- Disagree
- Strongly disagree

20. What do you like about the look of the padded belt hip protector? (List up to three features).

_____

21. What changes to the look of the padded belt hip protector would make it more appealing to you? (List up to three changes).

_____

22. What three words do you feel best describe the appearance of the padded belt hip protector? (Write the first words that come to mind).

1st word... *

_____

23. 2nd word... *

_____

24. 3rd word...

_____

25. Comparing the underwear and padded belt hip protectors, select the statements that apply to you. (Tick all that apply and please type in the 'Other' box any other relevant scenario).

- I would prefer to wear a hip protector that was hidden under my clothes.
- I would wear a style of hip protector that was visible over my clothes if I liked its appearance.
- If I were to wear a padded belt hip protector I'd wear it under my clothes.
- I wouldn't care what the underwear hip protector looked like as it is hidden.
- Other

Airbag Hip Protectors

Recently, a few manufacturers have developed hip protector belts, containing fall sensing technology, that are worn over clothing. When the sensors detect a fall happening, airbags automatically rapidly

inflate to provide protection around the hips. If you're not already familiar with these types of products, try an internet search using the term "airbag hip protector".

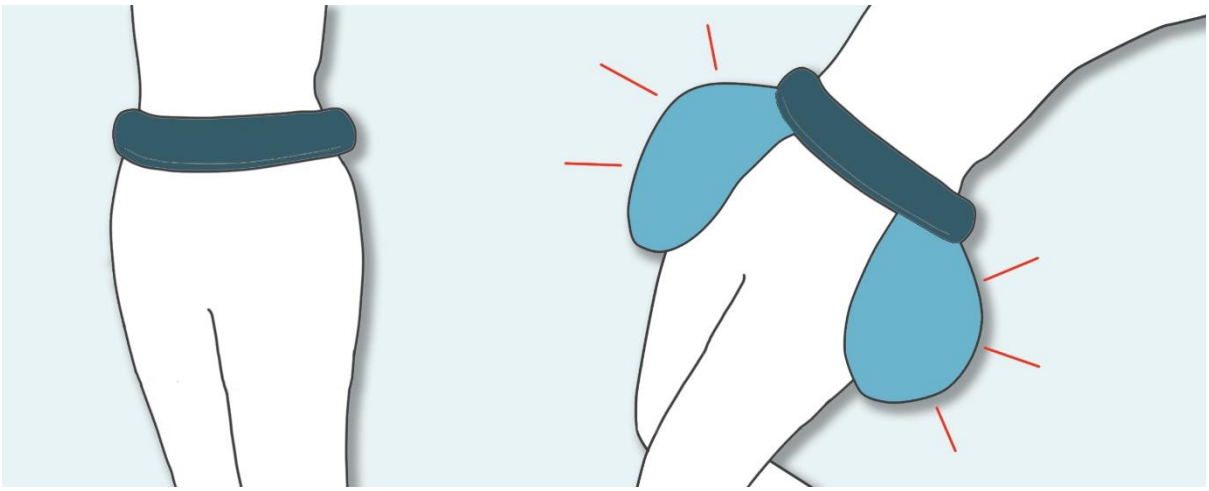
These products have been demonstrated to offer higher levels of protection from the risk of hip fracture compared with underwear or padded belt hip protectors.

Some other key differences are:

+ They cost around 10 times as much to buy compared to underwear or padded belt hip protectors.

+ They use a rechargeable battery.

+ They use a compressed gas cylinder that needs to be replaced after every airbag activation.



Alt text: An illustration of a figure wearing an airbag hip protector. Another figure is falling and the airbags are deploying.

26. Would you be prepared to pay significantly more for an airbag hip protector compared to an underwear or padded belt hip protector?

- Yes
- No
- Maybe

27. Please explain your reason for your last answer?

_____

28. Would you be put off using an airbag hip protector because you always have to make sure the battery is charged?

- Yes

- No
- Maybe

29. Please explain your reason for your last answer?

_____

30. Would you be put off using an airbag hip protector because you need to replace the compressed gas cartridges every time the airbag is activated?

- Yes
- No
- Maybe

31. Please explain your reason for your last answer?

_____

Re-thinking hip protection

In this final section, we'll ask some questions about your lifestyle that will help to inform new ideas for the design of hip protectors.

32. If you do use a hip protector now, or if you were to use one in the future, when would you most likely wear it? (Tick all that apply and please type in the 'Other' box any other scenario).

- When I go shopping
- When I'm doing gardening
- Generally around the house
- Whilst I'm at work
- Whilst exercising
- At night time
- All the time
- Other

33. Reflecting on when you would most likely wear a hip protector, what would be your style preference for one worn visibly over clothing or integrated into outer layers of clothing? (Tick all that apply and please type in the 'Other' box any other style).

- Bold

- Casual
- Colourful
- Cool
- Elegant
- Feminine
- Masculine
- Medical
- Quirky
- Relaxed
- Simple
- Sophisticated
- Sporty
- Understated
- Other

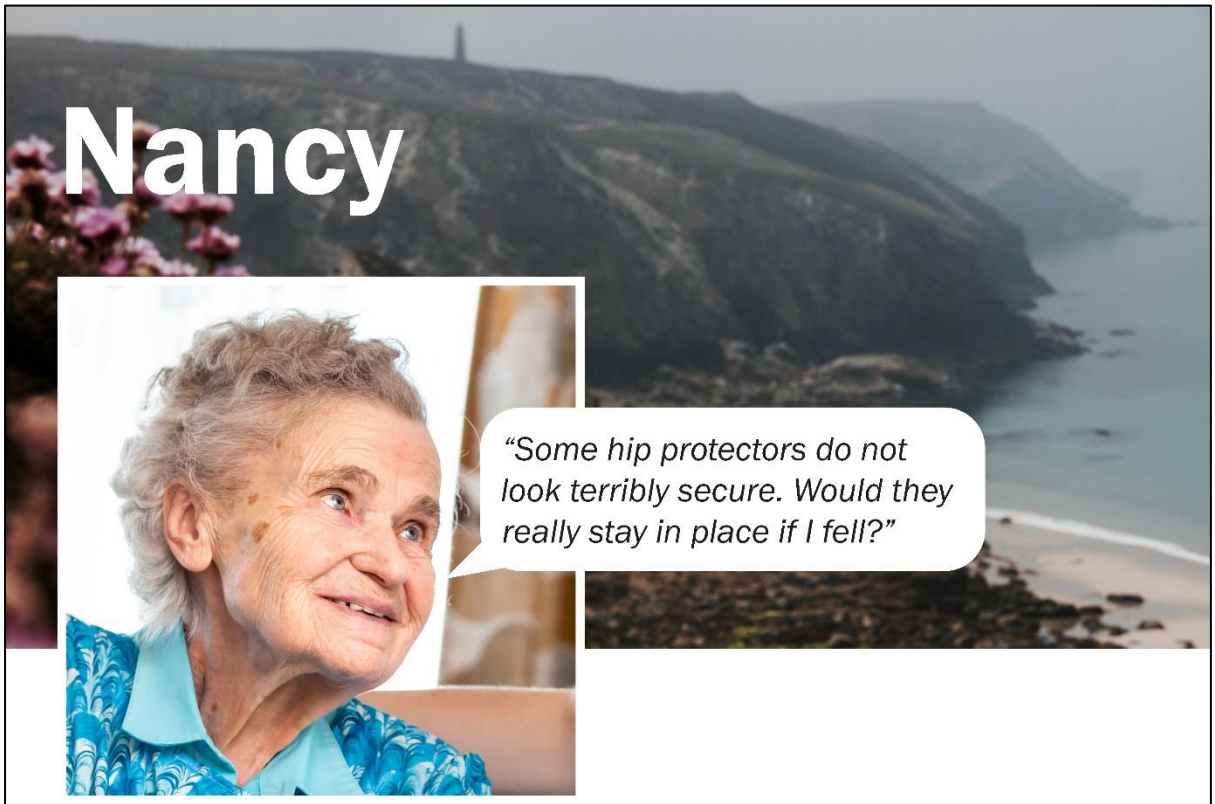
34. Some criteria for hip protectors may be more important to you than others. Place these criteria in order of importance to you, with the most important at the top to the least important at the bottom (click and drag the scenarios below to re-order them).

- It's easy to put on or take off
- It's comfortable to wear
- I like the way I look when wearing it
- It's no more expensive than regular clothing

35. If you have any further comments on the design of hip protectors and your preferences between them, please add them here:

_____

8.9 Appendix I - Personas



Audience
Encore phase - aged late 70s to end of life.

About
An 88 year old widow who has recently moved into an assisted living apartment. She has lived in Cornwall her whole life.

Personality
Insightful with strong principles and beliefs. She values honesty and authenticity but is also private and often finds it difficult to open up.

Interests
She has always enjoyed walking the Cornish coast and sea swimming. Her reduced mobility has made this more difficult recently.

Social environment
She has a son who lives nearby but spends quite a lot of time on her own. She often feels lonely but is beginning to make new friends with residents where she lives.

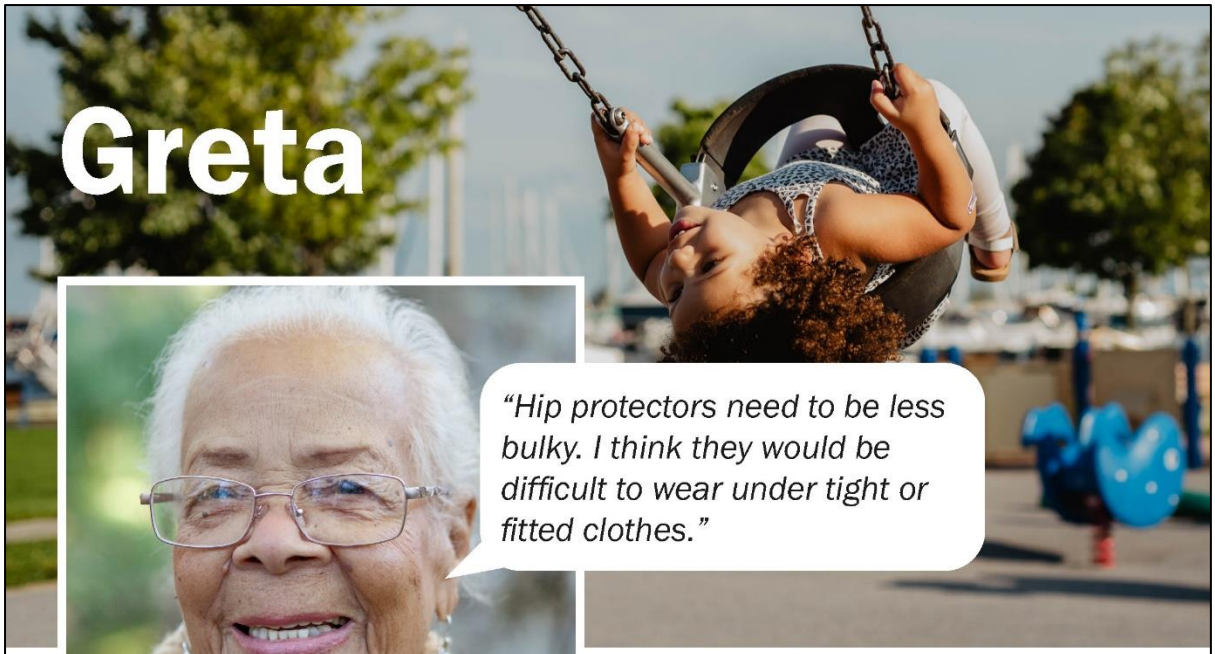
Why I'm interested in hip protection...

"I definitely feel much more wobbly when walking than I used to. I've had a few minor falls but I'm worried that they could become more serious."

What I want from a hip protector...

"I would prefer to wear a hip protector that was hidden under my clothes, but they need to be much more slimline. Simple and understated is the way to go."

Figure 120: Example of the persona 'Nancy'.



Audience
Summing up phase - aged mid 60s through 80s.

About
A 77 year old retired teacher who lives with her husband. They rely on a fixed income and have to budget carefully.

Personality
A reliable and supportive person. She truly enjoys helping others but sometimes overcommits and is unwilling to ask for help herself.

Interests
Has a keen interest in the arts and enjoys theatre and music. She began painting and drawing in later life.

Social environment
Family is very important to her and she is a dedicated grandmother. She has one or two close friends but mostly spends time with her husband, children and grandchildren.

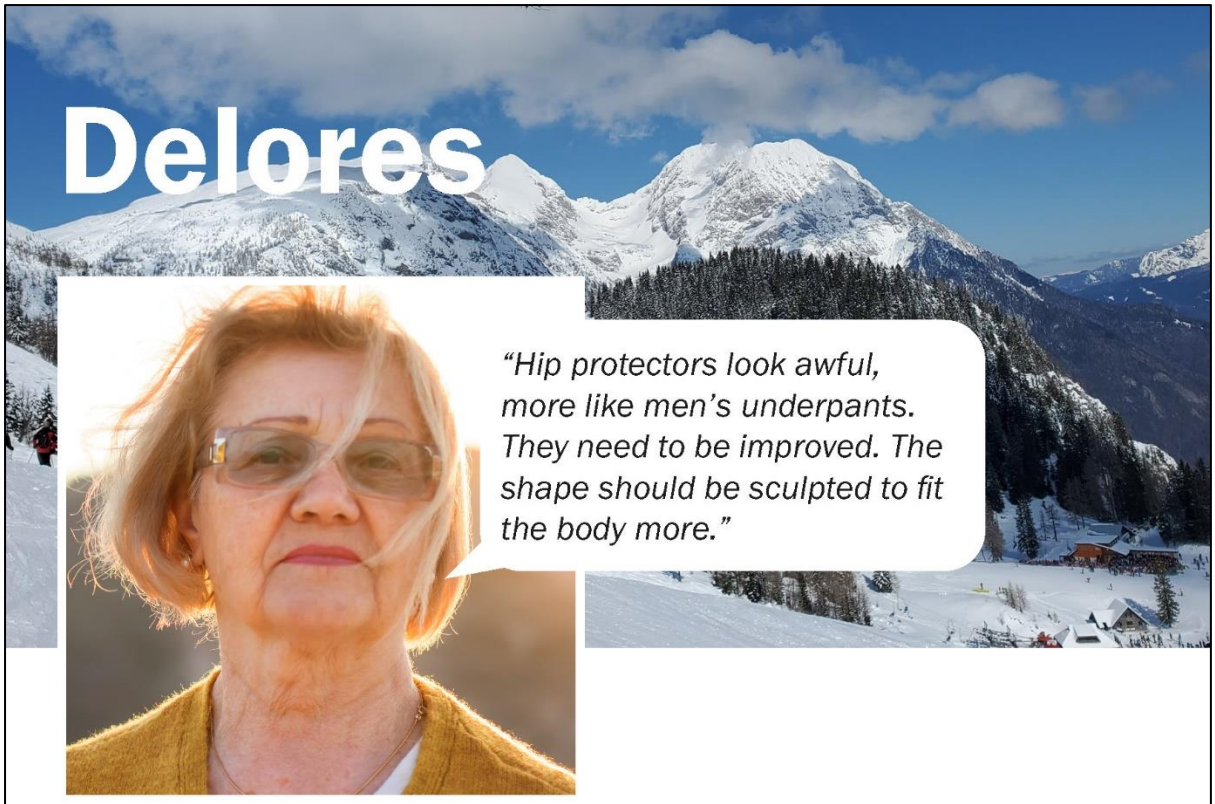
Why I'm interested in hip protection...

"I'm aware that age is a risk factor but I also have severe osteoporosis. Last year, I fell and fractured my hip."

What I want from a hip protector...

"The most important thing is that you can't tell a hip protector is being worn, and that they are comfortable and effective. Some peace of mind when I'm out and about would be good."

Figure 121: Example of the persona 'Greta'.



Audience
Liberation phase - aged mid 50s to mid 70s.

About
A 66 year old, recently retired environmental consultant who lives alone. She is looking forward to spending more time relaxing and enjoying life.

Personality
Warmhearted and approachable, with an altruistic spirit and a friendly disposition. She can be a little unfocused and disorganised at times.

Interests
Has always lived an active life, loves being outdoors and travelling. She learnt to ski as a teenager which is a passion that has remained with her since.

Social environment
Recently separated and looking to forge new connections and friendships. She regularly meets for walks with a local ramblers group.

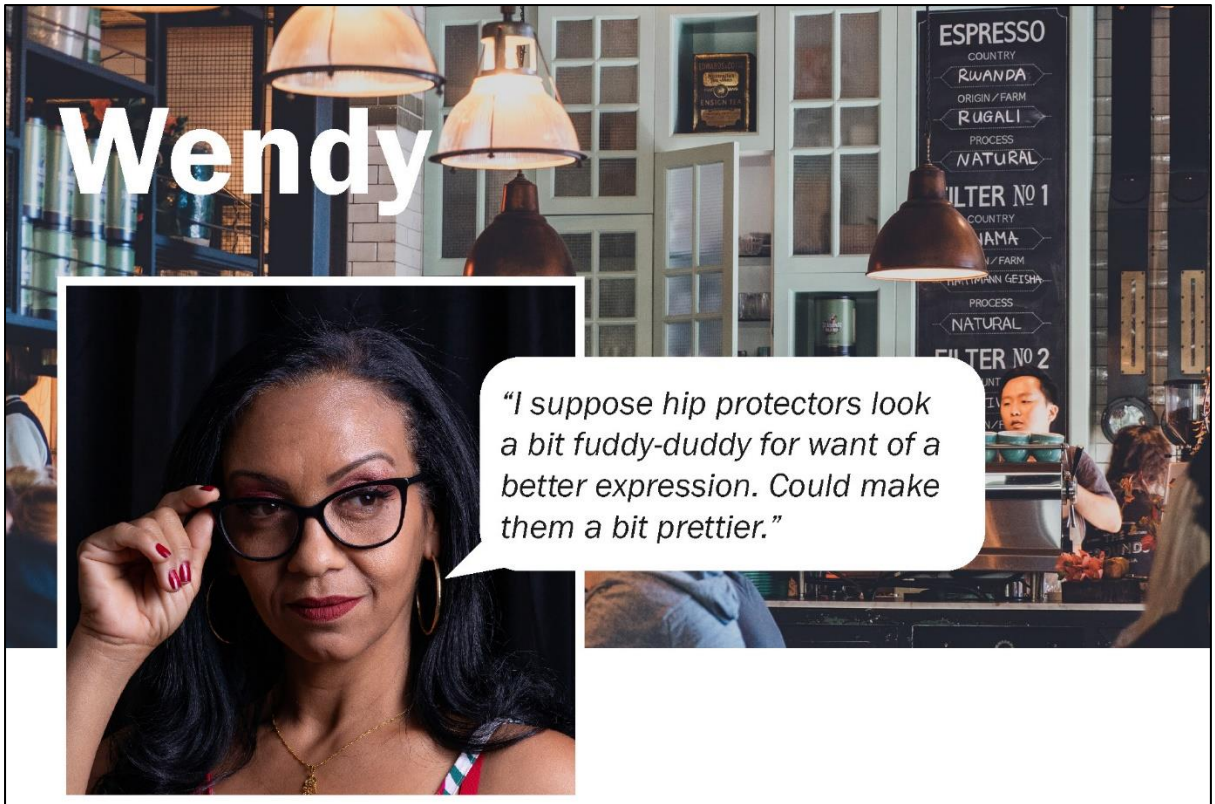
Why I'm interested in hip protection...

"I had an unexpected fall last year that has really affected my confidence. I was also recently diagnosed with osteopenia."

What I want from a hip protector...

"Cyclists wear padded shorts when sitting on a saddle. I was thinking that the hip protection might look something like that. Something that would not affect your exterior appearance and with a woman in mind - like a legging."

Figure 122: Example of the persona 'Delores'.



Audience
Liberation phase - aged mid 50s to mid 70s.

About
A 54 year old administrator working full-time for a local FE college. She has two adult children who have recently left home.

Personality
A very loyal, patient and reliable person. She's very independent but can often be quite stubborn and inflexible.

Interests
Enjoys being outdoors and walking every weekend. She is often too busy for hobbies but does enjoy eating out, socialising with friends and shopping.

Social environment
Lives with her husband and sees their children every couple of months. She has a close network of friends and colleagues who live locally.

Why I'm interested in hip protection...

"I am finding it hard to accept that I am getting older and have had osteoporosis since the age of 52. As I've become older I sometimes feels less stable on my feet."

What I want from a hip protector...

"I would love a hip protector that didn't make me alter my wardrobe. Skirts or dresses that were designed with integrated hip protectors in a chic way would be something nice to have."

Figure 123: Example of the persona 'Wendy'.

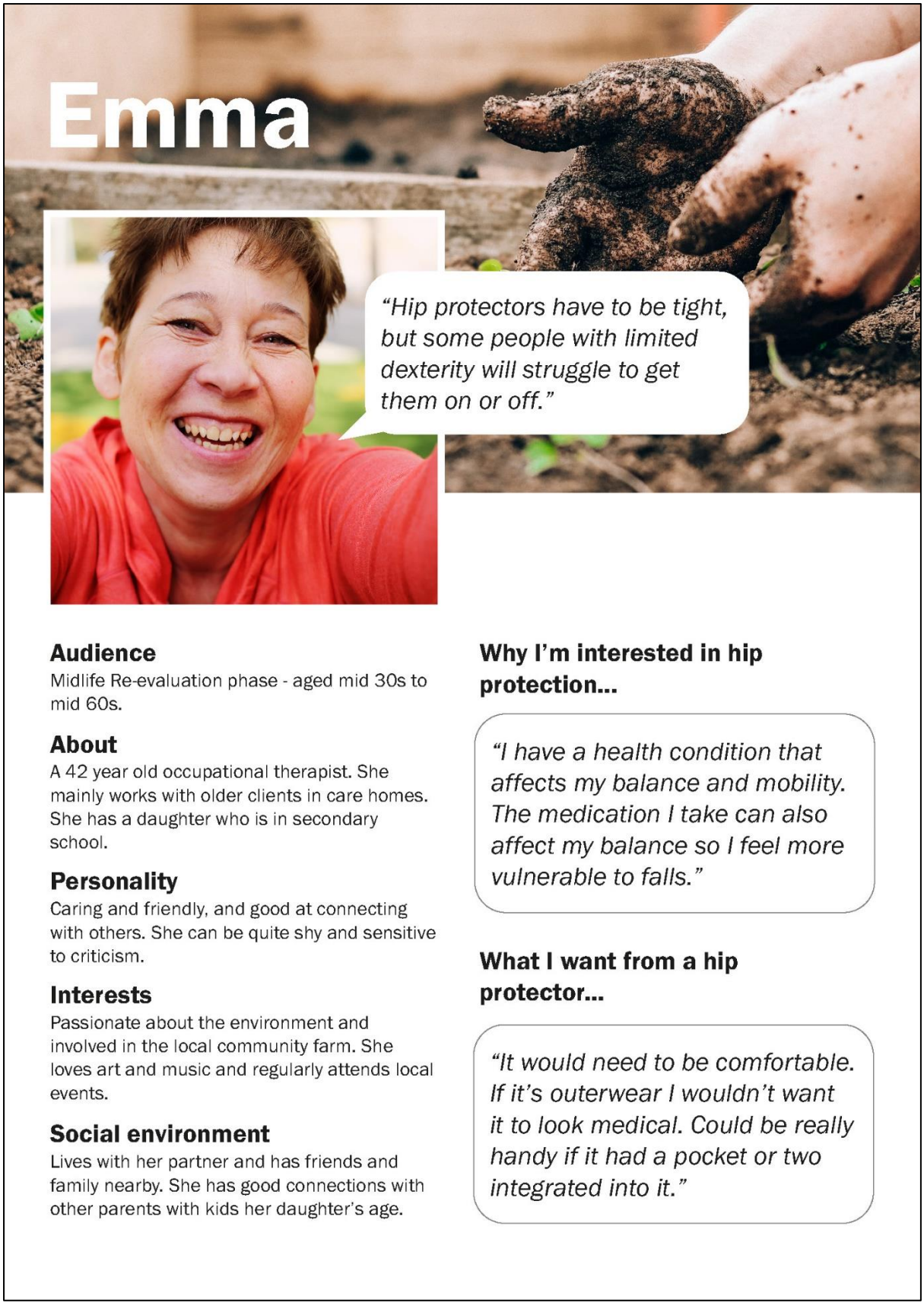
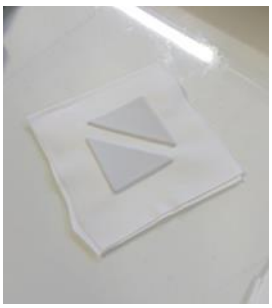


Figure 124: Example of the persona 'Emma'.

8.10 Appendix J - A summary of methods used to create test pieces relating to four design concepts

Concept	Materials	Processes	Research question
Inflatable surfaces (see 5.2.2) e.g. 	2oz PU Coated Nylon (black) – water resistant fabric (also airtight) with good strength and tear resistance (Profabrics 2024). 3mm poplar laser plywood – lightweight, rigid material suitable for laser cutting.	Ultrasonic welding – Sew Systems Ltd SSU-015R Ultrasonic Machine (Sew Systems Ltd 2023). Creates welded seams to join polymer-based fabrics. Seams are airtight unlike sewn seams. Laser cutting – Falmouth University's laser cutter. Plywood templates cut. Used to draw ultrasonic welded seam patterns directly onto the PU coated nylon with a white pencil.	<u>Performance requirements beyond reducing hip fracture?</u> <u>Investigating:</u> 1. Lightweight protection. 2. Easier to put on/take off deflated than tight fitting stretch garments. 3. Compression qualities of inflated garment could offer proprioceptive feedback. <u>Embodying a visual language that sensitively reflects the sociocultural and lifestyle aspirations?</u> <u>Investigating:</u> 4. Hidden/discreet protection integrated into clothing.
Protective tiled surfaces (see Appendix) e.g. 	3mm poplar laser plywood – lightweight, rigid material suitable for laser cutting. Calico Medium – versatile fabric used for constructing prototype clothing.	Laser cutting – Falmouth University's laser cutter. Plywood tile profiles cut. Used to simulate profiles that could be 3D printed directly onto fabric. Plywood tiles bonded onto calico fabric using PVA wood glue.	<u>Performance requirements beyond reducing hip fracture?</u> <u>Investigating:</u> 1. Easier to put on/take off garments worn over clothing. 2. Potential for 'hard shell' hip protectors to feel softer.

  	PLA 3D printing filament (white) – reliable 3D print with high dimensional accuracy and good surface finish (UltiMaker 2024a). 100 gsm Polyester Sportswear Mesh (olive green) – fabric used for linings and athletic gear (UK Fabrics Online 2024). Mesh fabric chosen to help adhesion when 3D printing directly onto the surface. TPU 3D printing filament (white) – a flexible material ideal for applications that demand the qualities of rubber or plastic (UltiMaker 2024b).	3D printing, Fused Deposition Modelling (FDM) – UltiMaker S5 3D printer (UltiMaker 2024c). Tile profiles 3D printed in PLA directly onto fabric placed on the printer bed. Tiles designed to be self-supporting so no 3D printed support structure was needed. Tests with Sportswear Mesh and Calico Medium fabric to explore adhesion of 3D print. Explored 3D printing tiles in TPU onto thin base layer (0.27mm) to create the same arrangement from a single material.	<u>Embodying a visual language that sensitively reflects the sociocultural and lifestyle aspirations?</u> <u>Investigating:</u> 3. Visual characteristics of patterned surfaces. 4. Making the protective element a more holistic part of the overall visual language of the garment. 5. Hip protector garments worn visibly over clothing.
Laminated padding (see 5.3.1) e.g. 	IGLO Heavy Polyester Lycra (white) – with four-way stretch suitable for swimwear and sportswear (Friedmans 2024). 5mm neoprene (black) – chosen to simulate thickness and weight of Poron XRD impact absorbing foam. An open cell urethane whose manufacturer claims it can absorb up to 90% of intense impact force (Rogers Corporation 2024).	Fabric adhesive bonding and pressing – Ardmel HSP-500 Pneumatic high pressure press (Ardmel 2024). Laminating neoprene panel between two layers of Lycra.	<u>Performance requirements beyond reducing hip fracture?</u> <u>Investigating:</u> 1. Compression qualities of stretch fabric could offer proprioceptive feedback. <u>Embodying a visual language that sensitively reflects the sociocultural and lifestyle aspirations?</u> <u>Investigating:</u> 2. Visual characteristics of patterned surfaces. 3. Making the protective element a more holistic part of the overall visual language of the garment.

			4. Hidden/discreet protection integrated into clothing.
Flexible 3D printed lattices (see 5.2.1 and 5.3.3) e.g. 	iMaterialise flexible TPU – flexible thermoplastic polyurethane, now discontinued. iMaterialise 'Rubber-like' (MJF) – a strong, highly flexible, shock absorbing and durable thermoplastic polyurethane (TPU) material (i.materialise 2024b). Formlabs Elastic 50A – for parts that will bend, stretch, compress, and withstand repeated cycles without tearing and return to original shape (Formlabs 2024c). Formlabs Flexible 80A – simulates the flexibility of rubber or TPU. Can withstand bending, flexing, and compression through repeated cycles (Formlabs 2024c).	3D printing, Selective Laser Sintering (SLS) and HP Multi Jet Fusion technology – Outsourced to iMaterialise, online 3D printing service. 3D printing, Stereolithography (SLA) – Formlabs Form 2 (now discontinued) and Form 3 SLA resin printers (Formlabs 2024d). 3D printing of flexible lattice structures with impact absorbing properties.	<u>Embodying a visual language that sensitively reflects the sociocultural and lifestyle aspirations?</u> <u>Investigating:</u> 1. Visual characteristics of 3D printed surfaces. 2. Making the protective element a more holistic part of the overall visual language of the garment. 3. Hidden/discreet protection integrated into clothing – reduced thickness compared to current hip protector pads.

8.11 Appendix K - A summary of CAD software used, process, and outputs throughout the design process

CAD Software	Processes	Outputs
Autodesk AutoCAD Used to create precise 2D and 3D drawings (Autodesk 2024b).	Created drawings for test pieces and prototyping using vector lines. Drawings saved as 'Drawing Exchange Format' (DXF) open-source files to be read by laser cutting software (Adobe 2024c).	Laser cutter: • Plywood drawing templates for development of inflatable surfaces. • PU coated nylon patterns for inflatable surfaces. • Plywood tile profiles for protective tiled surface investigation. • Lycra patterns for hip vest prototyping. CNC router: • Plywood components used to fabricate the drop test rig for mechanical impact testing.
Autodesk Inventor Used to quickly model, simulate and communicate design ideas (Autodesk 2024c).	Imported 3D scan data of fashion mannequin to generate 3D models of hip protection shaped directly from the mannequin hip surface. Developed all 3D forms for protective tiled surfaces. Developed overall hip pad shape for test pieces and prototypes of flexible 3D printed lattice pads. 3D models saved as native Autodesk Inventor files (IPT). Exported as STL files for 3D printing as this is a universally recognised format for 3D printing (Adobe 2024b).	Preparation for 3D printing: • Components for protective tiled surface investigation exported to Cura. • Parts designed to include an internal lattice structure exported to Netfabb or nTop. Concept visualisation: • CAD visuals of protective tiled surface. • Hip pad model exported to CLO to visualise integration with garment.
Autodesk Netfabb	Imported 'Initial Graphics Exchange Specification' (IGES) files from Inventor. Many CAD	Preparation for 3D printing:

This software was integrated into Autodesk Fusion 360 in January 2021, but was originally an independent program (All3DP 2022). Used for preparing, cleaning, slicing, toolpathing and simulating additive manufacturing (Autodesk 2024a).	applications support IGES, making the files simple to open across compatible software (Adobe 2024d). Developed early iterations needed to produce the flexible 3D printed lattice test pieces. Exported as STL files for 3D printing. Experimented with hip pad design with integrated lattice but found the software was limited by not being able to produce conformal lattices, i.e., lattice structures that follow the shapes of part surfaces. Only uniform 'lattice block' structures could be produced.	• Components for flexible 3D printed lattice investigation exported to PreForm. Concept visualisation: • Rudimentary CAD visuals of hip pad with integrated lattice.
nTop (formerly nTopology) Used to create complex geometries, to develop 3D-printed parts (nTop 2024).	Imported CAD models (Inventor IPT files) of test pieces and hip pad concepts that would include lattice structures. The software was used to convert a selected part of the solid model into a conformal lattice. The resulting lattice is joined to the outer 'skin' of the part (a separate IPT file import) using a Boolean operation. Exported as STL files for 3D printing.	Preparation for 3D printing: • Components for flexible 3D printed lattice investigation exported to PreForm. Concept visualisation: • CAD visuals of hip pad with integrated lattice.
Cura For 3D printing set up, management, and monitoring using UltiMaker machines (UltiMaker 2024d)	Imported CAD models (STL) orientated correctly, positioned centrally, and software diagnostics used to ensure an error-free print. Built using default settings for the UltiMaker S5.	3D printing: • PLA and TPU components for protective tiled surface investigation.
PreForm For 3D printing set up, management, and monitoring using Formlabs machines (Formlabs 2024b)	Imported CAD models (STL) orientated correctly and positioned centrally. On the hip pad prototypes, support material needed to be added so the part would not collapse during the build process. Software diagnostics were used to ensure an error-free print. Built using default settings for the Form 2 or Form 3 Formlabs 3D printer.	3D printing: • Flexible 3D printed test pieces and prototype hip pads.
CLO	Visualised hip protection garment patterns and assembled garment	Garment fabrication:

3D fashion design software used to create virtual, true-to life garment visualisations (CLO 2024).	concepts on male and female avatars.	• Garment patterns laser cut for hip vest prototyping. • Garment patterns for prototypes manufactured by DM Orthotics. Concept visualisation: • Photorealistic renders of garments concepts for evaluation and feedback.

8.12 Appendix L - Investigating 3D scanning

In this appendix, I report on my initial experiments with 3D scanning and the development of a workflow required to translate the scans of the body to the shape of a hip protector pad.

I used a hand-held Artec 3D scanner, connected to a MacBook Pro laptop (Intel Core i7 4th generation, 2.5 GHz processor speed) running the Artec Studio scanning software. The mannequin (see Figure 125) was set up in a space with at least 600mm clearance all the way round as this is the optimum scanning depth for the Artec machine. The laptop and scanner were set up on an adjacent desk with the cable length checked to ensure accessibility all the way round the mannequin without the wires from the scanner to the laptop and power supply snagging.

Figure 125: Fashion mannequin set up for 3D scanning with surface markers.

When scanning a three-dimensional object, the whole surface is not scanned in one go. Several separate areas may need to be scanned to capture the entirety of the object. These individual scan files are then mapped together in the scanning software to create a patchwork of the overall 3D model. It is useful to have markers applied to the surface of the object that can be used as a guide to align the separate surfaces in the software. I drew black dots onto squares of masking tape and applied them to the mannequin on the front and centre planes of the torso and the front and centre planes of the left and right legs. The dots were positioned outside the critical scanning area, just above mid-thigh and above the iliac crest and mid-torso. 3D scanners struggle with plain, smooth surfaces (inherent with the white, plastic mannequin) as they rely on changes in the surface colour or texture to map their location. For this reason, I also added vertical tape lines to create more texture on the mannequin surface.

Figure 126: Scan of the mannequin showing assembled surface mesh (left) and rendered solid surface (right)

The need for this surface treatment of the object to aid the scanning process naturally leads to questions of how this would be handled on a live participant. Tight fitting shorts or leggings could be worn with printed markers akin to the Japanese ZoZo suit (Nussey 2020). This could also provide a means of showing a precise position of the greater trochanter (which couldn't be established with the scanned surface alone), where the user could place a self-adhesive or Velcro marker directly over the point on their hip where they feel this bony protuberance. It's tempting to consider whether this exercise could be conducted independently by users at home using a smartphone app and system like ZoZo. However, for reasons of consistency, safety and liability, it would almost certainly have to be done by a specialist at a dedicated scanning centre.

Capturing the scan data proved to be a time-consuming process in itself. However, converting the CAD model to provide a functional pattern to project the shape of a hip protector pad also took some time. After mapping the individual scanned sections together, the workflow consisted of exporting the scan data from the Artec software as an STL file. This file was then converted to a surface mesh in Autodesk Inventor, using the Autodesk Mesh Enabler plug-in (see Figure 126). In this iteration, the CAD model was also converted to a solid body and trimmed above the 'waist' and below the 'thighs',

to remove the patchy scan data at the top and bottom of the CAD model, leaving a neater form to work with. The most significant impingement to the process at this stage was the large file size of the surface mesh at 101MB, which slowed down the software as it struggled to process commands. The file size can be reduced considerably before importing the STL file (e.g. using Autodesk's MeshMixer software) but this reduces the smoothness of the surface and makes it more faceted. A compromise was met between the optimum file size and high enough surface resolution with a 22MB file size.

Once the hip CAD model was imported and refined it was ready to be used as a pattern whereby the 'skin' surface on the hips (specifically the area of the greater trochanter) could be offset to create a surface object whose contours directly matched the corresponding surface on the mannequin (see Figure 127). This surface can be 'thickened' and then trimmed to shape to create the volume of a hip protector pad. The approach does rely on the anatomical accuracy of the mannequin, which cannot be verified, and the recognition that even if it did accurately reflect an adult female, it is not representative of an ageing body, or indeed the mean average size and shape. Nevertheless, the exercise still proved useful in understanding the process of body scan data capture and in a scenario with a human subject the greater trochanter location could be identified through the means mentioned earlier.

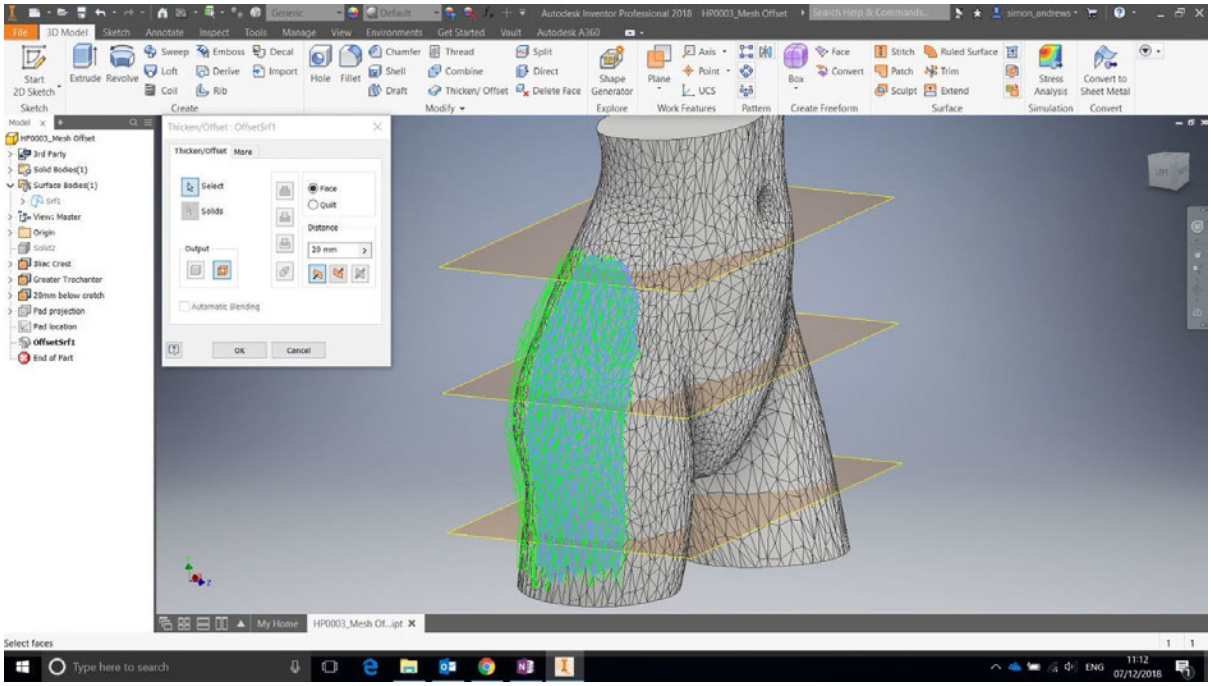


Figure 127: Screenshot of hip CAD model showing surface area of the hip offset.

Both Yahaya et al. (2021) and Park et al. (2019) also used 3D scanning technology and CAD software to create bespoke hip pad geometry that could be 3D printed, generated from a user's 3D body scan data. The former study went on to conduct impact tests on the 3D printed hip pad (produced using stereolithography in rigid VeroWhite resin) where it compared favourably to the HipSaver hip protector pad (one of the highest performing in terms of force attenuation in the study by Laing et al. (2011)).

A methodology for generating bespoke hip pad geometry, shaped to follow the body shape of the user, has been demonstrated through this process. The digital output of this geometry as a CAD file naturally leads to physical components produced through computer aided manufacturing (CAM). In particular, additive manufacturing processes would allow hip pads to be produced in a variety of rigid or flexible materials. Although Yahaya et al. (2021) found that a hip pad 3D printed in a rigid material demonstrated sufficient force attenuation to prevent a hip fracture, the viability of this as a realistic design solution is questionable. Not only could a hard material pressed against the skin become uncomfortable, but the rigid form would not accommodate changes across the surface of the hip as the user moved their body. This poses a fundamental problem with using 3D body scan data in this way as it only captures the hip surface shape in one position. The reality, of course, is that the hip is dynamic and subtle contour changes at the skin surface occur when we're walking, sitting, standing, etc. Using flexible 3D printed materials could provide a way of accommodating the shape of the hip as the user moves. Perhaps too, a combination of rigid and flexible materials could offer a solution that provides both impact deflecting and shape conforming properties. However, it may also be worthwhile to scan the user's hip in a range of different positions (certainly sitting, standing, and at a natural stride distance) and use a computer software algorithm to generate the optimum shaped hip pad for comfort and fit as the body moves. The use of flexible 3D printed materials is explored in chapter 5, which has prompted a more in-depth investigation into the use of lattice structures for absorbing impact energy, as demonstrated by (Park et al. 2019).

3D scanning technology is already being used commercially to capture user body data that directly informs the manufacture of bespoke fitting garments and products. The potential for its application for personalised hip protection products could be an opportunity to provide better fitting (leading to greater efficacy) and more comfortable garments. However, the hip region of the body is not a static shape and accommodations must be made for walking, sitting, and standing. This initial investigation into the practicalities of converting body scan data into manufacturable parts provides a workable methodology, repeatable at a small scale but unlikely to be viable if production volumes are higher due to the lengthy process involved. In this instance, computer software that can automate the process could potentially be employed. An algorithm driven approach could also incorporate other data relating to the user that isn't captured through the scanning process. For example, an individual's body mass index (BMI), or readings from a bone scan procedure (familiar to people with osteoporosis), could add more nuance to the hip pad specification than their body shape alone.

8.13 Appendix M - Under/Over/Outer focus group transcript

Transcript of focus group with four of the female participants from the iCareiMove exercise and balance class. Recorded 30th August 2019.

Researcher: Yeah, okay. So, right, this is, this is where we start. And so this, this idea is really based on where we picked off where we where we left off, rather with the garments that we were looking last time, so this is HipWear UNDER. And I can pass this round if you want to have a closer look. So. So this is, as we discussed, I'll pass it over to you in a moment. Separate hip protector garment and underwear worn together. I think one of the key criticisms that you raised with these was, if it's all one thing that becomes much more impractical to use. So what about something that's, that's separate. So worn under clothing during the day, and I've said it at nighttime, so possibly this, this is something that could be worn 24 hours a day, it's a two piece design, it's more practical and convenient than traditional hip protector underwear. So that it's kind of separate. And we're looking at low profile pads, with emphasis on discretion, and feminine styling. And with these boards I've got these are kind of like a sort of a scenario board. And get a sense of what what the design is. And in terms of starting to look at that as well. This is a kind of just a very brief kind of mock up of that sort of thing. So this actually it was produced by DM Orthotics. And I mean, obviously, there's no kind of detailing on it. But I think the intention here is, you know, how do we design something which actually just look looks like underwear as well. And it wouldn't be perhaps too much of a stretch to take something like this. And if you had a deep detailing like that, which was overlaid so that it had a kind of a more feminine style to it. Less, I suppose feeling like a kind of medical garment, but more something which you would just perhaps wear day-to-day anyway. And I've been looking at some other bits and pieces, and I'll show you these now before we discuss. But so these are some different types of 3D printed materials, which are where I'm looking at the the shock absorbing element.

Participant 2: That's better because I don't think those pads are resilient enough.

Researcher: Yeah. Well...

Participant 2: They'd have to be jolly thick to be practical. That's lovely.

Researcher: Yes. What I'm thinking certainly with that one is, it's probably not doing enough at the moment, with your point about resilience. But it has got a kind of silicon type feel to it. So it kind of feels like it sits in this area in terms of a little bit like, you know, like we saw on - and on your garments that you showed me earlier, Participant 1 - this kind of silicon strip on the inside, it kind of feels like a sort of material that you'd be okay to have against your skin. Yeah.

Participant 2: And easily cleaned, I would imagine.

Researcher: Yes. Yeah. This is something that DM Orthotics produce in some of their garments, which is a silicon backed mesh with flocking on it. So I was also thinking that maybe there's something in relation to that. And this and this, it kind of go go together.

Participant 2: This looks like speedos.

Researcher: Yeah. It does, doesn't it. So, perhaps if you want to, maybe before we start writing things, I'll put it back to you in terms of perhaps a three or four minute discussion around this as a starting point. What's your kind of gut feel about?

Participant 3: Well it's nice that they're looking at other materials, other than the heavier pads you showed us at first, and the complete garment to pull on. I think that's great. Especially if somebody wanted to do sports, and they weren't sure if they would fall over, or even skiers and places like that, you know, that is wonderful.

Participant 2: I think speaking day today, I had a terrible fall in Truro, main street. I caught my toe on the stub between the curb stones, and I went flying in front of hundreds of people. But I was prepared to go out for lunch. So I dressed up. Would I put something that wide, extra, on the hips that I'm already trying to get down? I don't think if I was going out anywhere, I would wear anything that protruded. And that feels lovely, and it's practical, but that's bulky and I don't think I would wear that. I think also, going into Truro, where the cobbles are even worse than Falmouth, you go almost prepared for a fall, do you? Or do you completely forget falling?

Participant 3: No, I don't forget falling in Truro.

Participant 4: Well, I'm in a wheelchair all the time. I would never even attempt to walk. Well I just know I couldn't do...it terribly.

Participant 3: Well that major fall I had was in [indistinguishable] road, which I couldn't... I mean, they kept asking me, was the pavement broken? Was there a hole in the road? I don't know what was there and wasn't there? You know, I just fell but I fell flat on my face. But I had osteoporosis and I didn't know it.

Researcher: Right.

Participant 3: So that's why both shoulders broke, because I never picked up my arms. And then when, because I had broken this finger and two toes and this finger on this hand, all the year before. And nobody looked at osteoporosis. They waited till I fell on my face and didn't pick up my hands. This one's metal. This one's not metal, but that one can go higher than this one can. And they also stopped my tablets last year, well the beginning of this year, because after five years your osteoporosis tablets that they give you to suck or to take every week, or every day, turn your bones to chalk. They have discovered after five years.

Participant 2: Typical. See, I think that adds considerable measurement to the hip line. I think if you were skiing or doing some activity where you knew there was... I could see it in a sporting situation but not in an everyday situation.

Participant 1: See, I'm so different because I've always worn something pretty much from a very, very young age. Seven, whatever, yes. And they were awful garments. This one I wouldn't want it here. I would want it up here.

Researcher: Right.

Participant 1: If it's just me, I don't know. But that's quite restrictive.

Researcher: The pressure on the tummy can can feel uncomfortable.

Participant 2: Yes, the waist is more used to it.

Participant 1: Yeah, where as here, I'm full of scars, and I know look fine. I've got more scars than I care to mentioned. So for me, that wouldn't work. I wouldn't want it there. I would have to have it up on the waist. It's difficult if I don't wear a belt. I mean, if it's very hot. Then my hernia's going to get worse and worse. And what do I want? I can't have surgery. They won't operate on me unless I'm dying, literally. So for me, it's worth the effort of wearing something to protect. If the hernia is getting bigger...

Participant 2: But this isn't what's being discussed now, is it. That's a different issue.

Participant 1: It is. But what I'm saying is if I was an elderly person, and the chances are I might fall and break my hip, I think, for myself, that I would wear something.

Participant 3: Well you see I'm in that - I mean, I over 80 now - I'm in that frame of mind now. And I think I should be protecting myself. That's why, I was talking about, I'm wearing trainers, now outside. I've not got them on today because it doesn't work in there. But I can walk better in the trainers than I can in any sort of shoes.

Researcher: So it's a preventative measure?

Participant 3: It's a preventative thing. So for my feet, it's a preventative thing. So I don't fall.

Researcher: Yeah, yeah.

Participant 1: So it depends on, at the end of day, how much do you want to save yourself?

Researcher: Yeah.

Participant 1: You know, when you're older,

Participant 2: Would it save your hip from breaking if you went down with a wallop like I did? I was telling you just now, after the fall, all the carers were wonderful, they they washed my blood away, and everything. They were terrific. But a car driver said, Are you going to be down there long? As I was on the floor, and he said, I need to move my car, and my feet were protruding and he took my two legs, and he moved them back. Now, had my hip been broken, what would he have done? But

you've got this happening. You've got idiots around. But I think in general, these pads aren't wide enough and they're not deep enough.

Researcher: Yeah, like we said last time with that product, I think certainly their sales literature, kind of talks about the extent to which they will protect against hip fracture. Of course, if you have osteoporosis, then you're more, you know, then, I guess a hip fracture is more likely than if you if you don't. So you could argue that in certain conditions, you might need more protection than otherwise. And that might be something about this project as well, where actually what you end up specifying is very personalised to you, based on your body size, your medical condition, where you are in your life stage as well, so that it becomes a personalised product.

Participant 2: Yeah. That looked awkward for Participant 1 putting it on. This with an opening is better.

Researcher: Yeah. Okay.

Participant 2: I couldn't get both legs up high enough.

Participant 3: No, no. That's things that I don't do.

Researcher: Okay.

Participant 4: You see, I think for me, personally, I wouldn't wear anything like that, as a preventative, that I'd be worried that my hip would go or whatever. And I would only wear it if I did do something to my hip.

Participant 2: As a medical thing...

Participant 4: and then wear it, but...

Participant 2: You would wear it for curative reasons rather than protecting?

Participant 4: Yeah. And that's how I feel about it. It's probably the wrong way to feel. But I mean, I've got osteoporosis, which was diagnosed but I didn't have any problem. I was in Tennerife on

holiday, fortunately for a month, and my back went while I was over there, and hospitalised and everything. It was absolutely shocking. I mean, I couldn't get on the thing to get x-rayed or anything without screaming and they got annoyed with me, and it was awful. And when I came home, well we were going to come home early and then we said no. We've hired a car. We'll grin and bare it for the last week, blah, blah, blah, came back. And yes, I had to pay for it, but I was scanned straightaway, and diagnosed with osteoporosis, which I hadn't a clue I'd got.

Participant 3: No, this is it. They don't test anybody for osteoporosis until they've broke something.

Participant 2: I feel, look as I slap that... There's no protection there.

Researcher: Oh, yeah. No, that's more of just a sample.

Participant 2: But I like the thought of that. It's more hygienic, I think, than something dense?

Researcher: Yeah. I'm very interested in that as material and the potential breathability of that as well.

Participant 3: Yes, that's what I said...

Participant 2: But it does contract very, very easily. I don't have to put much force on it. So as you land on the ground, would it help your hip?

Researcher: Not that, no. At the moment, no.

Participant 2: I don't think so.

Participant 3: It depends on the way you land.

Researcher: Yeah, I think the point about this as a sample was really looking at different ways of approaching the impact protection. Because this is 3D printed, this can be this could be manufactured in any any shape. It could also be manufactured in the shape that fits your body perfectly, because it can be made around 3D scans of your body. So, it's much more sophisticated technology than this, but certainly doable. And so that's an interesting area of research. Yes. So, just

going back to this then, we've got probably, maybe a few more minutes, just on this one. I've just been jotting some notes down as we've gone along. But let's, just kind of recap in terms of what do you think some of the strengths are in this?

Participant 3: Well in style it's better for females, definitely, than trying to pull a pair of pants up.

Participant 2: It needs to open easily. And have a higher waist band.

Participant 3: Yes, if you want to put that bit. Depends where they say your hip is...

Participant 1: Yes.

Participant 2: I wouldn't like the cost of it to increase enormously just to put lace over it. I think it's such a practical thing...

Participant 3: Yes, that's right.

Participant 2: ...it doesn't need to be to pretty.

Researcher: Okay. Yeah.

Participant 3: It depends what age you are.

Researcher: I think it's more about it just having...

Participant 3: How you feel...

Researcher: Some kind of detailing which moves it away from that into something which is...

Participant 2: And the appeal to sell it.

Researcher: Yeah.

Participant 2: If it looks prettier people might buy it more, readily?

Participant 1: Yeah, that that looks...

Participant 3: Masculine.

Participant 1: Well it does look very masculine.

Participant 2: But it looks sporty. And I think, you know, if I was going into a sporty situation, which I don't anymore, that that would... that looks business-like, that looks efficient, but it's very thin.

Researcher: But this is something, I guess, which would be under your clothes as well, so only visible...

Participant 3: Under trousers.

Participant 4: You could have lace over the top of it.

Researcher: Yeah, yeah. It could do.

Participant 3: It could either be tarted up, I say.

Researcher: But I think... Yeah, okay.

Participant 4: I mean, not on the top of that. I mean, you're not gonna wear anything like that without pants on.

Researcher: Yeah. Yeah. Yeah.

Participant 4: Which with me, I think would be lacey. I know I'm 80 or over, but, I like everything like that. You see, I always have. Because I'm older...

Participant 3: It doesn't stop you at all.

Participant 4: It doesn't stop the way I want to feel.

Researcher: I think the point is that... what I think, in terms of encouraging people to want to wear something like that from a proactive point of view, I think one of the hurdles to start off with is actually is it something I'd want to wear anyway.

Participant 3: That's right.

Researcher: You know, regardless of how well it protects me. So if we can start talking about these products in slightly different ways, so that it doesn't feel like a medicalized thing, but something which is more about your lifestyle, that you would kind of wear on a daily basis, because it fitted in with, you know, how you feel about yourself and what you want to wear and what you enjoy wearing, then that feels like the right direction.

Participant 4: Yeah,

Participant 2: If one particular firm was producing that to help people with osteoporosis, say, and it's a medically approved something, if they produce trainers or shorts or jogging bottoms with a pocket in you could then get the pad to fit your needs, and your shape.

Researcher: Yeah, yeah. Yeah.

Participant 2: So if it was pre designed, with a pocket, rather than put on an extra garment.

Researcher: Okay.

Participant 3: Do you mean pockets in the tracksuit bottoms?

Participant 2: In the bottoms, yeah.

Participant 3: Well, they'd need to be like fitted ones that they're doing now. Like, you see the girls with the fancy leggings on with the different colours that could quite easily...

Participant 1: They're quite expensive though, and would you want to wear them every day?

Participant 3: No,

Participant 1: You really wants something that you can put on

Participant 3: under a skirt even...

Participant 1: See, I would put that with my pants on top of it anyway.

Participant 3: Yes. Yes.

Participant 1: Because you're not going to...

Researcher: Well, that's an interesting question, actually, because in the illustration there the pants are underneath.

Participant 1: But you can't get them off.

Researcher: Yeah. Yeah. So that wouldn't work then?

Participant 1: No, not like that.

Participant 3: Well, I think if the pants were underneath you could pull the pants away, underneath. The way ladies sit down now, they don't pull... they pull trousers down, but you wouldn't pull a waistband thing down, would you.

Researcher: Yeah, OK.

Participant 2: I think you need the pants over then it's just easier then out.

Participant 1: That's what I do. I have the pants on over the belt. Because then the belt stays in place and I haven't... Because even with the Velcro, if you take the Velcro off, you're in the toilet, you've got nowhere to let it rest.

Participant 2: No, you can't put it on the floor.

Participant 3: No.

Participant 1: Well, you wouldn't want to.

Participant 2: No, no.

Participant 1: And it's... Because you can get a material that is...

Participant 2: But would I want all that non-slip stuff next to my skin? I think I might react against that.

Participant 1: I think that's too much. I think you would need some.

Participant 3: Is there any on that one?

Participant 1: There's none on this one.

Participant 3: No, it's just elastic.

Participant 1: But if you have, like I have, have it here, it's surprising what you get used to.

Participant 2: Oh I appreciate that, yes.

Participant 1: Because it's so unusual for you. That's why I came because I wear a belt. Not because I... I have fallen. Lucky enough, I bounce... at the moment. But yes, I know I'm a different age group really, but because of the belt business, I thought I might be of some use.

Participant 2: I think in Cornwall we're particularly vulnerable because of all the cobbles.

Researcher: Yeah, yeah.

Participant 2: And councils put them down because they think it looks oldy-worldly. And it's killing people.

Researcher: Yeah. Okay. Yeah. All right. I think we've probably covered this one, that's really helpful. And yeah, that's a good starting point. So, we'll move on to the next one. And this is... So, we've got HipWear UNDER, this is HipWear OVER. Okay, so this is... what if we did put this over the top of a garment, rather than it being as underwear? And these are some examples. These things, I've taken off a website called Pinterest. So, which is...

Participant 3: Yeah, I know.

Participant 2: Yeah.

Researcher: Okay. So these are some existing things which are kind of like, what we might describe as a 'bum bag', but not. I mean, they're tailored...

Participant 3: They look as if they're a workman's tools pockets.

Researcher: Yeah, there is an element of that, isn't there. So this question then is about HipWear OVER. So to be worn out and about, or at home during the day, hip protection could be integrated into a garment worn over your clothes. Includes large pockets for a phone, purse, keys, etc. Tailored to look like a garment, not a bum bag. Which, last time when we spoke, we were kind of talking about this having a connotations of that. It's a bit sporty.

Participant 3: Yeah.

Participant 2: You'd need them both sides, wouldn't you?

Researcher: Yes, yeah. I mean, some of those are kind of asymmetric.

Participant 2: I think as a crutch user - I use two crutches - that would be an additional thing to get caught up.

Researcher: Okay.

Participant 2: I don't think I would put that over any of my garments.

Participant 1: No, I wouldn't wear it at all. None of them.

Participant 2: Would you wear them?

Participant 4: Which one?

Participant 2: Any of them.

Participant 4: I might wear that.

Participant 2: It looks like a bandage.

Participant 3: Actually the little tartan one looks quite good if you're just protecting one area.

Participant 2: There's nothing to it.

Participant 3: Yeah.

Participant 2: That wouldn't prevent a break.

Participant 3: Yeah.

Researcher: Yeah. I mean, none of those are hip protectors at all. It's more about the notion of something which is worn to provide hip protection, but maybe offer something else, like bigger pockets, I suppose. Because lots of women's wear has small pockets.

Participant 3: Or no...

Participant 2: Lots of women's wear have no pockets, anywhere, which is a nightmare.

Researcher: And one of the things which strikes me as well about kind of mobile phone technology is mobile phones seem to be getting bigger and bigger at the moment.

Participant 3: That's right, yeah.

Participant 2: And heavy.

Researcher: And... yeah. And I wondered whether there would be something in this which had enough of a kind of practical element to it that would encourage its use?

Participant 2: It's easier to put on if you're going out suddenly, you could whip that on very quickly over your clothing. But I've got so many bits and pieces all over me, I don't know that I want to advertise another one.

Participant 1: I wouldn't wear it.

Participant 4: No.

Participant 3: No, I don't think so.

Participant 2: I wouldn't. Not outside.

Participant 4: No, I wouldn't. Sorry.

Researcher: What would be the reasons for not wanting to wear it? To wear something like that?

Participant 2: Well, it's another advertisement that I am old and I'm decrepid. And I don't want to advertise another problem, when it hasn't happened.

Researcher: Yeah.

Participant 2: Yeah, I've broken my hip and I've got an artificial hip. But I don't think any of these are sufficient to protect that artificial hip.

Participant 1: For me, I want to look normal.

Participant 3: Yes, that's it. Somebody would probably realise what it was.

Participant 1: Just, it looks out of place.

Participant 2: I mean that sort of thing, if you've got that both sides, people will think "what on earth is she carrying".

Participant 3: Well it's like the people that wear their haversacks at the moment.

Participant 1: Yeah.

Participant 3: They walk in front of you and go like that and you're the one that gets pushed away by the haversack. I often say, "excuse me your bag's just pushed me off this chair!".

Researcher: Yeah, yeah.

Participant 3: It's like this, do we need to be bigger to compete with handbags and bits, even men with their mobile phones?

Researcher: Yeah.

Participant 1: We all like to look nice, we all...

Participant 3: That's right.

Participant 1: And how many of those would you need to match different coloured outfits?

Participant 2: Yes. Yes.

Participant 1: Sorry, but that's...

Participant 2: That's true. That's another good point.

Participant 3: It's true.

Participant 1: It won't go with what we wear. For gentlemen, it's probably slightly different

Participant 2: And if you're carrying a handbag anyway you don't need all that as well.

Researcher: Yeah.

Participant 3: Well, apart from the handbag.

Participant 1: Yeah, just I don't think they would be as neat. It would stick out, as you say, and you'd be knocking...

Participant 3: The point being it'd be more padded than those.

Participant 2: I think at our age, we carry quite a bit of stuff around with us, at least I do, that as when hips and sprays and things, that I would have three lots of luggage on me.

Participant 3; Yes.

Participant 2: And two crutches. You'd look ridiculous.

Researcher: Okay. Yeah. All right. Any other positives?

Participant 3: You're sorry you came.

Researcher: No, no that's absolutely fine.

Participant 2: That would be accessible if you had one hanging in the hall somewhere, and you thought, "oh, I'm walking around X, Y and Z, perhaps I might fall". Easier to put on; that's my only positive for you.

Researcher: Yeah. Okay. We've got that. Yeah. And I suppose that kind of scenario where maybe you're going to Truro, you're going to go do some shopping, and it's something that, which...

Participant 2: It's where you're vulnerable.

Researcher: Yeah, yeah. Okay. All right. Any other any points? Any other negative points then? on this? Or?

Participant 3: Definitely, it has to be double sided if you're talking about hips.

Researcher: Yes, of course. Yeah. Yeah. And...

Participant 1: Generally people don't remember to go and put them on. I mean, a lot of people don't put belts on to prevent hernias. They just don't think about it. Like you said, it's by the front door, but you wouldn't keep it by the front door. So then it's...

Participant 2: It's another thing to have to think about.

Participant 1: You just won't remember to do it. You might think you will the first few times, but after that, it would be something that's a waste of money, because people wouldn't use it.

Participant 3: That's why this stays on all the time, because I'll forget to put you on it when I walked out the door.

Researcher: Yeah, yeah. Okay. What is that?

Participant 3: It's an alarm for in the house and in the garden.

Researcher: Yeah.

Participant 3: And I tap it and get either the people that I've got on my list will answer me, or the paramedics come and sort me out.

Participant 4: So what is it then?

Participant 3: It's an ALFI [assisted living personal alarm], yes. You can get things to hang around your neck.

Participant 2: Literally a lifeline.

Participant 3: It's a lifeline. And they can go in the shower, you don't take it off.

Participant 2: But that's when you fall.

Participant 4: A very good idea.

Participant 3: That's when you fall.

Researcher: Yeah.

Participant 3: People won't believe me when I say... what you don't take the lifelines off when they go in the shower and it's the one place they should have it. Now the paramedics in Truro, I noticed them one day looking at a lady's mobile phone. And I said, "are you looking up the ICE number?" And this guy said to me, "what do you know, about the ICE number?". In case of emergency. He said, "yes, you'd be amazed at the amount of people that don't have anything in there".

Researcher: Yeah.

Participant 3: And I mentioned it at the IT because I go to IT up here. And I think there was only four of us, out of 28, had an ICE number in. And when I got this two years ago, I got in touch with them and said, "can I make you my ICE number, because my son lives in Hertforshire?" And they said, "yes, certainly". Because they've got all your details and they can tell the paramedic or somebody that's picked you up off the street...

Researcher: Yes, that's very sensible.

Participant 4: For me, I didn't even know anything about it. I know about the lifeline...

Participant 3: It's very sensible. Well, they're the same. You can get...

Participant 4: ...because my mum had one.

Participant 3: You can get that as a lifeline but I didn't want it as a lifeline. I wanted it as a bracelet.

Participant 4: But she wouldn't push... press the damn thing because she didn't want to trouble anybody. Would you believe it?

Participant 3: Well what was the point of paying for it?

Participant 4: Absolutely.

Researcher: Yeah.

Participant 1: So my sister used it all the time.

Participant 3: Yeah? Well...

Participant 1: Because she kept fitting.

Participant 3: Well, this is it. I think it is a lifeline, what they call it.

Researcher: Do you think, in terms of that sort of technology, if there was something like that integrated into something like this...

Participant 3: Oh, yes. Excellent.

Researcher: That would be more of a motivating factor to use?

Participant 2: Could it be an automatic thing? It would automatically call paramedics if it had a certain degree of pressure?

Researcher: Yeah, yeah.

Participant 2: Because that's indicating a fall.

Researcher: Detecting falls, yeah.

Participant 3: And it's nice that it would be connected to information that they know about you. They've got to have the information to pass on to the hospital or whoever's taking you where.

Researcher: Yeah.

Participant 3: It's amazing the amount of people that don't know what this ICE number is.

Researcher: I've never heard it described as that.

Participant 1: No, I've not no.

Participant 2: Not heard it called that, no.

Participant 3: Right, look at your mobile phone and it says I-C-E. Where it gives you the list of contacts.

Researcher: Yeah.

Participant 3: I-C-E, and it means in case of emergency. So you should have somebody in there, in your mobile phone.

Researcher: I'll do that.

Participant 3: Yes, you learn something every day.

Researcher: So if we were thinking about it maybe more in terms of a full alert type thing, which is a worn thing...But maybe offered some protection as well? Would that feel...? Would you be...

Participant 3: Right.

Participant 2: More practical. It would be more practical.

Researcher: Yeah. Okay. All right.

Participant 2: I think also it would stop... In the instance of my fall, nine people rang for an ambulance. And that's taking all that time up, two ambulances came - I didn't need an ambulance in the end, I needed the little car - and I think it was... if it had some sort of warning in it, it would stop so many people feeling they were helping.

Researcher: Yeah. Okay. All right. That's okay. That's good. Thank you. Okay. We'll move on to the last one. So we've had under and over.

Participant 2: Inside?

Researcher: Yeah

Participant 3: I think we're knitting something!

Researcher: Ready... this is HipWear outer. So this is, I guess, it's kind of a, again, a bit of a rethink. So the potential of this then is a three quarter length outdoor jacket with integrated hip protection. So it's something that naturally falls over your hips. And inside it has an inflatable apron that wraps around the hips that's completely hidden under your jacket. The apron can be inflated or deflated with a hand pump or blow tube. So you control it. It's not an automatic thing, necessarily. The inflated apron provides impact protection, but it can also provide compression, and insulation. So there's an idea there about it, again, adding more kind of value to what it actually does. The compression thing is quite interesting, because as soon as you apply compression, it works a little bit like the things that DM Orthotics design, which are about creating better balance and proprioception. If you've got that compression. The other thing is actually, it creates natural insulation. So you'll have warm, you know, it'll keep you warm around you. So the... an idea for this then is that we briefly discussed last time inflatable hip protectors - there are these kind of airbag type things. That's not what I'm proposing here, that's a different thing. So they automatically jettison, if you fall over. The idea about this is it's something that is built into the garment that you can sort of control and use if you want to or not, if you don't. What you can see in this image here is, this is a ski jacket, which has got a belt underneath, which is called a snow skirt. I don't know if ever been skiing before? But so this is a kind of elasticated waistband that pops underneath and it just stops the snow going up your back if you fall over, yeah? But it's underneath the jacket. So it's a similar kind of principle. Right, you're going to laugh now because I've mocked something up. It is

very, very crude, okay, but, but bear with me, bear with me. This is my jacket. So the idea being... yeah, know..

Participant 1: That looks lovely!

Participant 2: Looks like a dog bed!

Researcher: It does a bit doesn't it! Not sure what the provenance of this towel is, but...! So the idea being that this thing is kind of something that you wrap around you underneath.

Participant 3: Yeah.

Researcher: Whether it velcros or poppers or zips? Not sure. And then obviously, the jacket would be a little bit longer anyway and that would come down over the top. And then maybe it's got a hand pump but that might be difficult to operate, maybe it's automatic, maybe there's a blow tube, a little bit like a life jacket. It wouldn't take very much air to fill it very quickly.

Participant 2: So that's purely precautionary?

Researcher: Yeah, but it's precautionary in that this could be designed in such a way that the inflated bit, is obviously very lightweight, so it's not like this, it's using them, but the inflated bit will be over your hips. But also you could have inflated elements all around your waist...

Participant 3: Yeah, you could have it all...

Researcher: ...and your coccyx, for example.

Participant 3: That's right.

Researcher: And - I'll take this off now - but...

Participant 3: Well modelled!

Researcher: I've been doing some experiments as well around this sort of technology. So the idea that when this - I've got a few of these but I'll just show you this one - when this fabric inflates, these chambers can be designed in such a way so that it goes from a flat material to something which has shape to it. And it can be designed so that it has... it can create curvature in more than one direction. So a kind of hyperbolic... And you do this by the actual... the shapes that are effectively heat sealed together with the material. I'll give it a demonstration. Again, this is all very crude, so you're going to have to use your imaginations here. But the idea being that as soon as a fabric like this inflates. See that kind of wraps over? So imagine this on a slightly smaller scale, a little bit like the detailing on this jacket here, where actually as you blow into it, the shape will fit your body. And again, this could be designed so that's done at a bespoke level. So your own measurements can be done to fit snugly on you.

Participant 4: Well of all the things. Which one would I choose?

Participant 3: The jacket.

Researcher: I don't know.

Participant 3: The jacket. I think the jacket sounds good. I think the idea of it blowing up, could be anywhere in the jacket.

Participant 2: I wouldn't walk around with an area blown up around me cause I'm trying to lose weight, and that adds it back on. But if I fell, I wouldn't be able to then inflate it. It wouldn't have a purpose.

Researcher: Well, I thought that maybe if, in that lining, it had... it also had something which was maybe a very thin, there's some inherent padding in it already, perhaps. Although that does slightly draw away from the practicality of it being completely inflated, yeah.

Participant 3: But if the way you designed the small bit you've got, if that was like in a pattern. If that was on, I don't think it would be that big?

Researcher: Well, I think it wouldn't need to be very big at all. And it will probably, under a jacket like that which which could be tailored in such a way so it does flare from the waist, that it would help to kind of disguise that sort of, that bulkiness.

Participant 3: I think the inflating idea is the best one you've had.

Researcher: Okay.

Participant 2: I don't think so. I don't think, if I was going out I wouldn't inflate it in case of.

Researcher: So they're... I guess maybe the... Would you inflate it because it helped keep your hips and your waist warm? And would you inflate it because that compression would help kind of with your hip stability?

Participant 4: I would want it for the compression, for protection and feel.

Participant 2: Maybe...

Researcher: Because one of the things that we've talked about before in terms of compression garments is that they can be very helpful. But because they're tight to put on, they're difficult to put on and take off. Whereas something like this, where you put it on loose, but then you blow it up and that that compression comes in...

Participant 2: I think another thing that's embarrassing to mention, but at our age group, my age group, so many people, male and female have incontinence problems. So they're already wearing gadgets, shall we say. And then to have a another one that they've got to worry about or have a carer put on. It's giving extra work.

Participant 3: Yeah but if this is a jacket or a coat you wouldn't need a carer to put it on.

Participant 4: If you fell anyway, you were on your own and you fell, and you had that...

Participant 2: It's instant protection isn't it.

Participant 4: There's loads of people on the street and it's not blown up, it's easy for them to just blow it up or activate it, isn't it. Whatever you've got.

Participant 2: If you're with family who knew what it was.

Participant 4: Or you wouldn't... I mean, the ambulance crew and all that would...

Participant 2: Yes, they would know.

Participant 4: They will know. And also...

Participant 3: I would keep it blown up all the time.

Researcher: Yeah, I think...

Participant 1: I think you've got to really.

Researcher: This is the idea that it's...

Participant 3: Because it's so minimal, like what you've done there. But that is amazing that the pressure that it gives you to save you from...

Participant 2: That protects more than just two little pads.

Researcher: Yeah, I mean, it might be that it has to be designed in such a way that these are a series of panels, and maybe there's some elasticated stretch between them.

Participant 2: Yes, yes.

Researcher: I think if it was like a thing that was blown up all around it would be quite restrictive.

Participant 1: Oh, yeah, because how would you sit?

Researcher: Yeah, quite. Yeah. And that's something which I haven't even thought about yet. But it's a really good point.

Participant 1: Yeah.

Researcher: And so where the inflated channels are, would have to not impede on your walking and sitting and general kind of movement. But it could be designed in such a way so that these will inflate and curve and curve in the right places, and but then be linked with a kind of a stretchier material.

Participant 1: The biggest problem I see is... would be expense.

Researcher: Yeah.

Participant 1: It would be incredibly expensive and I don't think... It would be...

Participant 2: Oh, yeah.

Participant 3: Astronomical.

Participant 1: It would be very expensive but also you wouldn't be able to get it on the NHS because they wouldn't pay for something like that.

Participant 2: No.

Participant 1: So it's not going to be for that many people that would want to pay.

Participant 2: They only pay for treatment not precautions. But this, if it had a sporty connection and it's aimed at ramblers where you are likely to fall, therefore you will always keep it inflated. I could see people being attracted to it because they... It has the sporty connotation. If people are watching football matches, it's going to be cold, they'd like the extra protection from the weather, and from the rain, you know. It's got sporting... more sporting connections than everyday wear.

Participant 1: Also it will be something that it's only in the winter, when it's very cold.

Participant 3: Yeah that's true.

Participant 1: To be honest it doesn't get that cold in Cornwall. It gets very wet. So I think the practicality of it outweighs the benefit of it because you've got to pay for a coat. You've got to have that extra bit put in. I just...

Participant 3: Yeah, I see what you mean.

Researcher: So how would we get around that, do you think?

Participant 2: Well, we come back to another garment which is inflated all around instead of two little pads. Like a little crinoline underneath your skirt.

Participant 1: Yes, but, but I'd be happy to walk around with that. But then when I got to the coffee shop, that we all do, I don't want to take my coat off and show everybody that I've got this. So...

Participant 3: I bet you'd think, oh gosh, she's got thin.

Participant 1: I think it's a brilliant idea.

Participant 3: I think it's fantastic.

Participant 4: Hmm, yeah.

Participant 1: But I don't see the practicality at all.

Participant 4: That wouldn't bother me, you see. It wouldn't bother me taking a coat off anywhere. And

Participant 3: Oh no

Participant 2: No, that's not the major feature.

Participant 3: I think it's...

Participant 1: But you're not, because, you know, if I'm walking around Truro, and I've, I'm going into have a coffee, then alright I'm happy to take my coat off. But I'm not going to sit there and take this off and then put it back on. Especially if I can't walk very well, so I've got to manage it while I'm sitting. And no, I just don't see the practicality of it on a long...and it's not...

Participant 4: So you'd have to be easier to get into the garment, then. If it's into the garment, it's got to be easy for me to get into the garment and just put it on to the garment and wear it and blow it up and on you go.

Researcher: Yeah, I mean, this... I think the kind of the seasonal thing is clearly an issue isn't it.

Participant 2: Yes, yes.

Participant 4: Yeah.

Researcher: But I suppose there are, you know... The jacket, this jacket or this jacket. There are... it could be any jacket. It could just be a thin.. you know...

Participant 2: Yes.

Participant 3: Showerproof...

Researcher: It could be a gilet type thing. There could be something which is, which is... In many ways it's more about the length of it, I suppose.

Participant 1: Yeah.

Researcher: And I wonder whether also the actual inflatable bit, if that is something that's poppered or zipped into the jacket, that might be removable, so it could be worn on its own? It could be worn with a different jacket? It could be worn with your favourite jacket? I mean, maybe it's...

Participant 3: Yes, yes, you've got it. Like a lining...

Researcher: It's something in terms of the expense, maybe something that could be retrofitted.

Participant 3: Yeah.

Participant 2: I think balancing cost, that would be...

Participant 3: Cheaper to do as a lining.

Participant 2: That would be expensive as Participant 1 thought. But you're not having to give it to a separate person where some of these shapes have got to be geared privately to you. And that is universal and multi sexed.

Researcher: Yeah.

Participant 2: Say multi sexy...

Researcher: Yeah, yeah. So I mean, yes, and obviously we have been looking at emphasis on on hip protection for women. But of course, all of these things can be gendered either way. But I suppose, well, that's a good question in terms of three-quarter length jackets. I suppose guys wear three-quarter length jackets, but probably not, maybe not as commonly in terms of this sort of wear. Maybe in terms of an overcoat...

Participant 2: I was thinking about a cotton... What's it called? Cotton Trader clothing. They have most of theirs unisex and they do have a...

Participant 3: They're coming down to pocket level on the gents.

Researcher: Yeah, yeah.

Participant 2: They can buy short or the same style, but in a different length. I think that would be accommodated. And you could have a universal one. You don't have to have it designed to you.

Researcher: Yeah.

Participant 4: See, my jackets are getting longer and longer.

Participant 3: Cause you're getting shorter and shorter...

Participant 4: I'm getting shorter.

Participant 3: Yes, yes. I've got that problem myself.

Participant 4: It is, it's true.

Participant 2: Yeah. Oh, yeah we're all shorter than we were.

Participant 4: Although, my back is straight, I'm not... you know what I mean.

Participant 3: Yeah.

Participant 4: I'm just lucky that way, but I'm still going shorter.

Participant 2: I've lost three and a half inches. I was only ever formally measured when I went to university, in the first health check. And then I got measured after my hip broke... broken and it's three and a half inches, which is a lot.

Participant 4: A lot, yeah. I was five one...

Participant 2: All my skirts grew over the winter.

Participant 4: ...and I'm four foot eleven and a half now.

Participant 2: Yeah.

Participant 3: We've all shrunk.

Participant 2: I think... I would disregard that completely.

Participant 1: Yeah.

Participant 2: But I think they're points for both of those.

Participant 3: Yes.

Participant 2: And I've got no real preference over them. Would I pay for that? Would I want a garment that everybody else is wearing? Don't know.

Researcher: Well, that's an interesting one as well, isn't it, because often with... if we look at fashion and trends, often that's an incentive, isn't it: oh, I quite like that jacket.

Participant 2: Yeah.

Researcher: And actually, perhaps, you know, maybe some of the stigmas around wearing a hip protector and feeling like, you know, what that means, could maybe start to break down. Like it was integrated into more of a mainstream...

Participant 3: I think if it was some sort of lining that you could put in yourself.

Participant 2: I think, yeah. A lining would be better.

Researcher: Yeah, OK.

Participant 3: A separate, very fine separate puffer jacket.

Researcher: Yeah. This has been really, really helpful, thank you.

8.14 Appendix N - Visual development and prototyping of the protective tile concept

A series of material experiments explored the potential of tessellated and overlapping tiles mounted onto a fabric or foam surface. I was interested in how these could provide energy absorbing protection through a flexible surface that could accommodate body movement. This concept was superseded by research investigating flexible 3D printed lattice structures. Nonetheless, the idea has the potential to be explored further, including mechanical impact testing to investigate force attenuation. The material experiments are summarised through the figures below.

Figure 128: Plywood laser cut tiles bonded onto calico garment side panel mock-up.

I initially experimented by bonding 3mm plywood laser cut tiles to a calico mock-up (see Figure 128). The calico pattern represented the underarm side panel of a vest or t-shirt with the tiles arranged to cover the hip area. Circles cut from white card were glued to some of the plywood tiles to explore how a shingling configuration might work. The flexibility of the tiled surface showed potential, but I was keen to explore more viable ways of achieving the affect. This prompted an initial investigation into 3D printing onto fabric.

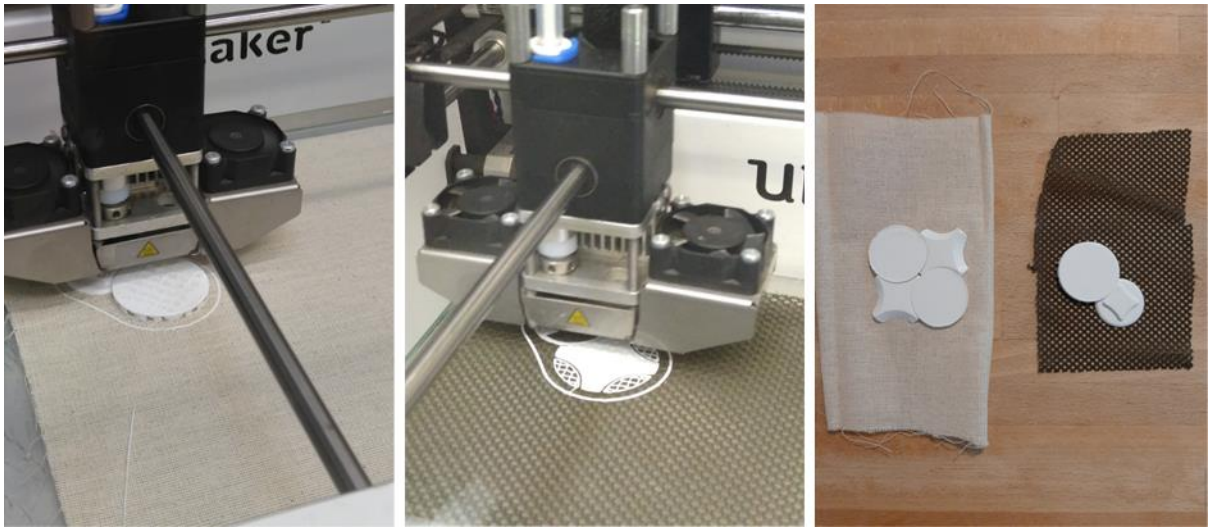


Figure 129: Experimenting with 3D printing directly onto fabric. Left, PLA printing on calico. Centre, PLA printing on polyester mesh. Right, finished samples.

Using an Ulitmaker FDM 3D printer, I tried 3D printing the tile profiles in PLA directly onto fabric placed on the printer bed (see Figure 129). The tiles were designed to be self-supporting, so no 3D printed support structure was needed. I tested the process with Calico Medium fabric and polyester Sportswear Mesh to explore adhesion of 3D print. In neither scenario did the PLA bond very well to the fabric and it could easily be peeled off. The unreliable adhesion would be a problem for the security and longevity of the product.

I conducted further material experiments with plywood by stacking and glueing the laser cut tiles to simulate other geometry that could be 3D printed. Although these too were bonded to calico, this work led to later 3D printing experiments in flexible TPU where surface layer was an integral part of the 3D print. The mock-ups had a pleasing visual effect with the tiles akin to fish scales. The tiles neatly followed a gentle curved surface (see Figure 130) but the shingling could easily become unmeshed if the fabric was pulled over an uneven surface (see Figure 131). I looked to resolve these issues with the later 3D printing experiments.

Initially, I considered how the tiles alone could provide energy shunting or absorbing properties, but later reflected that the surfaces could be backed by energy absorbing foam to potentially improve their force attenuation performance.

Figure 130: Detail of plywood laser cut tiles bonded onto calico.

Figure 131: Plywood laser cut tiles on calico placed over uneven surface.

Figure 132: Samples of 3D printed tiles with integrated flexible surface. Left, PLA tiles on TPU base layer. Right, TPU tiles on TPU base layer.

I developed the shingled tile design, evolved from the laser cut plywood samples. This consisted of a singular tile shape that could self-tesselate. The tiles overlap at the intersection between the edge surfaces that slope inwards and outwards. I explored two iterations of this design (see Figure 132): one version where the rigid PLA material was printed directly onto a thin (0.5mm) flexible TPU base layer; the other version where the whole part was printed in flexible TPU. The rigid PLA version was considered to provide energy shunting properties if the surface was backed by an energy absorbing foam layer. However, like printing onto fabric, problems with adhesion between the two materials were encountered. The sample produced entirely in TPU was more effective in this capacity, but the tiles are a softer material.

This speculative exploration of the protective tile concept concluded with a scaled-up version of the TPU sample above. This considered how the tiles could form a flexible protective surface laminated over an energy absorbing foam layer (see Figure 74 in section 5.3). Notionally, the pattern of the tiles could provide a visually pleasing surface to the protective layer, especially on hip protector garments, worn visibly over clothing, such as a belt.

8.15 Appendix O - Hip Vest feedback interview responses

A summary of participant responses to the interview questions.

Participant 1 - Recorded 5th March 2021.

- Initial thoughts and reactions to the product? What three words best describe this product?
    - "I thought it looked very practical, very wearable and suitable for men and women."
    - "Practical and wearable."

- What might be the advantages and disadvantages of this product compared to underwear hip protectors?
    - "The difficulties I thought was, everybody's got different body lengths."
    - "Because I wear a vest like this to support my hernia. So, I'm aware of the negatives of getting these things on and off as well."
    - "I wasn't sure how flexible it would be for how you sit and you stand."
    - "That's the one thing I'm a bit concerned about is the flexibility of it as you sit down, and you stand up. And also when you're walking whether it would rub your skin at all."
    - "The advantage, I think, is it looks very wearable. That was one of the things I thought, it looks normal. I'd be happy to be seen in something like that."

- What type of fabric would you expect it to be made from?
    - "And so it would wash better, I think it needs to be a mixture of cotton, mostly cotton, because it's nice and cool. But Lycra as well to keep the shape."

- What are your expectations of the padded area? Hard, soft, rigid, flexible, how thick?
    - "It's difficult because you can't hold it and touch it. But I thought you wouldn't want it too thick, and not too heavy."

- "I wear tube belts as well and to keep those in place we have like silicon strips around the top and the bottom, so that you pop it on and then it sits in place. I don't know if anything like that would be of help to you?"

- Where would you expect to buy this product? What brands might you associate with it?
    - "For something like this, I think you'd probably go to a pharmacist. But it depends if you're going to prescribe these for people."
    - "You might need to measure people because, for the tube belts and the other belts I wear, a measuring company comes to measure me to get the right size. And I think because of the different lengths of our bodies if you were going to do it in a vest that might be necessary."
    - "Maybe Boots as a company, if they were... if you could take them off the shelf."
    - "I don't think I'd want to go into, say Marks and Spencer's and pick these up. I don't think... I don't know. But I think it's to do with the sizing, be quite difficult."

- What would you expect to pay for a product like this?
    - "How much we pay for them, for a vest, I would pay £35 for the specialist vest. But they also do them in a pack of four for £100."
    - "I think the tube belts are about £45 - £50, and a slightly different belt that they do is about £55."

Participant 2 - Recorded 19th March 2021.

- Initial thoughts and reactions to the product? What three words best describe this product?
    - "When I saw the image my very first reaction was, "oh, that's better" from the ones we'd seen before"
    - "It was clever bringing in colour, because I think it makes it more appealing, but I don't think those are the colours that would sell well."

- "I think it has to be more generic, it has to be black, grey, navy and cream, which is the basis of a woman's wardrobe, and the man's really, and then build up from there."
- "I wondered about it curling up with movement, because it goes over the groin."
- "The actual fitting of a vest top, I like because I wear a camisole. I don't know whether, summertime, people would want to wear that extra layer."
- "I think the first appeal seeing the illustration, I would give that a go. None of the others really appealed to me at all."
- "Smooth", "comforting", I feel, and "smart".

- What might be the advantages and disadvantages of this product compared to underwear hip protectors?
  - "If it had a panel across the tummy, as well. I think that would, for a woman, be protective and help pull the tummy in, which would be nice. Perhaps the protection bit could go right across, and the two areas join up?"
  - "That would appeal to a woman, I think more. We're always aware of our weight, particularly this year." [ref to shapewear]

- What type of fabric would you expect it to be made from?
  - "I think it needs to be stretchy. It needs to be non-fluff making."
  - "It must resist curling up. It mustn't ladder, and it mustn't chafe on the seams."
  - "I think it's got to be something like an original corset fabric, which is an awful fabric, but it's robust. I mean, ladies wore their corsets for years. And I think it has to be something of that line, it's got to have some sort of, I feel, sheen on it, or polish on it to slip on the body so it doesn't grip."
  - "It's got to have manmade fabric. I would love to think it was full cotton, 100% cotton and absorbable, but I don't think that would wear very well for any length of time."

- "I think you've got to be aware of the bindings of the straps and the lower area. If it's bound, it's got to be something that is acceptable to the protective area. And I don't know what that will be made of."
- "I think under the arms and around the bottom, I think that's got to be a very robust binding but non-chafing and non-hurting."
- "What about if it was made, particularly the protective areas, if it was [a] surface with something that was spongeable, that would be better than having to continually wash the whole garment, where water might be absorbed by the protective area and take a long time to dry."
- "it's got to have something that will be totally non-abrasive, to those of us who have had hip surgery. And we're protecting our hip surgery, that's why we buy it, because we don't want to go through all that again."
- "I think it would have to be something very, very soft inside. But again, still waterproof and still spongeable, and that's tricky."
- "I think something shiny, that would slide over the skin, and over the scar, is a must."

- What are your expectations of the padded area? Hard, soft, rigid, flexible, how thick?
  - "it has to be resistant. It has to be soft for comfort. I think to get a marriage of the two would be really quite tricky."
  - "a thick sponge, a manmade sponge, covered in a sort of filmy stuff, like plastic, which is spongeable, and I think after every wearing, even during wearing sometimes if it's very hot, one would need to sponge it down, so it's got to be waterproof."
  - "it just doesn't look as though the protected area is very deep. How would it resist, like my fall on the curb?"
  - "I think I wouldn't bother to undress to put the camisole on, but I would probably quickly whack a belt on, if I thought I was going for instance into Truro which fills me with terror now, with the cobbles."

- Where would you expect to buy this product? What brands might you associate with it?
    - "Well obviously in one of these awful catalogues that you get for disabled people, but they're useful, they sell useful aids, and this would be also useful."
    - "Possibly in a store somewhere where they have a special disabled area where they sold special built-up shoes and things like that. Or chemists."
    - "I think immediately Marks and Spencer's. If they took the idea on that would be wonderful because everybody would see it male and female, but I think that's going too big initially, isn't it?"
    - "I think also if you could get John Lewis behind you. Their publicity machine is so good."
    - "Oh, I could see it there, easily." [ref the product being in M&S or John Lewis]

- What would you expect to pay for a product like this?
    - "If this was protected so that it didn't have to be worn daily, so it didn't have to be washed after every single wearing. If it could be reliable, that it would last a lifelong time, then I would be prepared to go to £28, that came to my mind."
    - "Well, the Marks and Spencer's camisoles which are the exact same shape as the top of this thing, there in the region of £10.99 - £12.50."
    - "I think I would go up to mid-30s because it would be a one-off purchase."
    - "I wondered if they were worth selling in the three main medium, dark and light colour range and sell three as a time?"

Participant 3 - Recorded 26th March 2021.

- Initial thoughts and reactions to the product? What three words best describe this product?
    - "I thought it was really attractive and practical and simple. I don't know how you came up with such a lovely design."
    - "I wouldn't complain about wearing anything like that because it didn't look like a surgical garment."

- What might be the advantages and disadvantages of this product compared to underwear hip protectors?
    - "Thought it would easily come on and off so it wouldn't be a deterrent for any lady that wanted to wear it."
    - "It didn't have a surgical look."
    - "I think the colours of what you supplied on the picture were very nice, and it also could give lots of extensions to that, if somebody wanted it in a different colour."
    - "How are they fitted in? Are they loose? Or are they part of the garment?"
    - "Having it very difficult to launder, I mean, thinking back to when I used to wear padded bras, no matter how careful you were with them, washing them, they sometimes changed. Either the texture changed or the colour."

- What type of fabric would you expect it to be made from?
    - "I think the actual fabric would need to be the one that is around everywhere, the Lycra nylon, but it'd be lovely if it could be a cotton knit to be cooler if you know, that it was going to get used 24/7, or whatever. But that might be quite difficult."

- What are your expectations of the padded area? Hard, soft, rigid, flexible, how thick?
    - "I think it has to be flexible. I know it's very difficult to be flexible and, you know, less elastic if you can gather what I mean?"
    - "But it needs to have something like that, because nobody would believe that it works if it's not got a bit of firmness."
    - "If you're using it as an undergarment, it can't be that thick because nobody wants to be bigger than they actually are."
    - "But if it was a nice fit for them, they wouldn't mind a bit of thickness, I don't think."

- Where would you expect to buy this product? What brands might you associate with it?

- "Well, I think you'd have to make it available at high street stores, so that the lady that wants to buy it for the first time doesn't feel... It's going to be a bit more expensive, but she doesn't want to lay out a lot of money if it's not going to be for what she wants."
- "I think she would have to go to, obviously, a store that does specialty things. I mean I was going to suggest Marks and Spencer's."
- "It depends who would make it at a reasonable price, and be adequate for what you want and tick all the boxes."

- What would you expect to pay for a product like this?
  - "You could take a number out of a bag and it'd be right. But it would need to be, I think, between £20 and £30."

Participant 4 - Recorded 19th March 2021.

- Initial thoughts and reactions to the product? What three words best describe this product?
  - "Well, I was quite impressed really with them. I thought they were quite - for what they are - I thought they were quite modern."
  - "I quite like the look of them."
  - "If I needed something like this or, you know, support, yes I would definitely look at it, because it doesn't look to me, cumbersome."

- What might be the advantages and disadvantages of this product compared to underwear hip protectors?
  - "The top of it really is just like a sports top really isn't it."
  - "It quite surprised me when I opened the page up that it's something for someone that's, you know, like me, disabled. I mean I don't need hip protectors at the moment, the way I am, but I was pleasantly surprised with it."

- "Well, yes, although I'm elderly. You know, I like anything that is, how can I put it, um, not "old-peopley" if you understand. Does that sound sense, Simon?"
- "I'm not old fashioned in my dress whatsoever. You know, I've always been the same that I like to look very smart and that hasn't left me, thank god, now that I'm eighty something."
- "It looks for me as if it will well serve the purpose, but it also looks feminine as well."
- "Well, with me, it looks as if it wouldn't be hard to put on, if you understand me?"
- "But I would want to wear underwear, you know pants, over the top of it, not put pants on and then put this over the top of the pants."
- "It would be easier for me to put over my head like I'd put a jumper."
- "I mean, you certainly don't need to wear underwear under them. You don't need to wear a bra under it."

- What type of fabric would you expect it to be made from?
  - "It's hard to explain, but with it being like it is, I'd want a certain firmness there. Certainly, if I had a problem with my hips, I would have to have a firmness there."
  - "a fabric easy enough to, you know, put over my head and pull down."
  - "Yeah, definitely." - when asked if she thought of it as the same fabric as a sports vest

[There was some confusion when talking about the fabric of the garment with the material that the padding would be made from. I had to lead the questioning a bit more here].

- What are your expectations of the padded area? Hard, soft, rigid, flexible, how thick?
  - "So, there's one, two, and then the third one is going around the back, isn't it?"
  - "I thought that was another piece that went just a little bit further around. Not actually onto the bottom but a little bit further round, you know, but obviously it's not. But I personally think that that would be adequate as it is."

- Where would you expect to buy this product? What brands might you associate with it?
    - "I thought: a sports shop. Then I thought no ridiculous, ridiculous to me."
    - "Marks and Spencer's would be the place for me to go, because that's where I buy all my underwear, always have done."
    - "I feel that I benefit far better going there, somewhere, you know, in my own Marks and Spencer's where I'm known anyway, cause Truro's so small […] That's what I would want to do. That's the first place I would want to go."
    - "I don't know much about sports brands really... Looking at that, as soon as I saw it, the top, the bra part just looks sporty to me."
    - "With Marks and Spencer's, I just feel that I could go in there and if the product is there, I'll get all the help, if I needed it."

- What would you expect to pay for a product like this?
    - "As things are today, it would be well over, well over £25-30."
    - "To be honest, I wouldn't have a clue how much I would pay for, you know, a sports vest or anything. I just would not have a clue."

8.16 Appendix P - Product user evaluation feedback forms

Hipwear prototype evaluation form – Participant 1

Before taking part in the evaluation, please carefully read through the questions below. Where possible, complete each section 'in the moment'. If necessary, use a notebook or voice notes to record your observations to complete the form later.

Participant name:	**Date of evaluation:**	**Time garment put on:**	**Time garment taken off:**
[Participant 1]	20 / 05 / 2023	12:30 PM	5:00 PM

Putting the garment on:
Place under your normal clothes. Make sure pads are positioned over your hip bones. Pads and lower part of the garment should be tucked into your clothing and not visible.

1. How did it feel putting the garment on?

The garment was slightly frustrating to put on, as when I began to put it on I had not decided what outfit to wear with it yet, so it was difficult to try on different outfits with it on, especially taking on and off jeans. This is because every time I would pull my jeans up, the pads would get in the way and pull up to my waist, instead of staying on my hips.

2. How easy or difficult was it to put the garment on?

Slightly difficult, mainly for the reasons outlined in the question above.

3. How did the garment feel once it was on?

The garment felt comfortable physically once on, psychologically I was a bit more wary, as I was questioning whether or not people would notice larger hips than usual. This is due to the shape of the pads, which were quite blocky. Once I got used to wearing it, I did not physically notice the pads as much, as I became more used to the feeling. However, it was definitely still noticeable. Material-wise, the garment is very comfortable, and I feel it would remain so even in different temperatures and activity levels.

4. Did wearing the garment influence the choice of clothing you wore over the top? If so, how?

Yes, it did. Jeans and other trousers were not as viable as a flowy skirt, as they hugged my hips more and it was definitely a noticeable size difference from usual. Additionally, because of the shape of the pads (which I am aware are only test pads) again were very blocky, and therefore showed the size/ shape difference more.

5. Any other observations or unanticipated experience putting the garment on?

No, the main thing would probably be the difficulty in the actual pulling up of jeans/trousers while using them.

Participant photo:

6. Add a photo of yourself fully dressed for the day with the garment hidden under your clothes. Use your phone and a mirror to capture your shoulders to knees.

Wearing through the day:
Keep on for the whole day if possible. Be aware if the pads move and are no longer over your hip bones.

7. Describe your day; what activities have you done?

I woke up very late and lounged around the house for a while after I woke up, at which point I put the hip protectors on. I did a combination of standing and sitting while around the house, doing a few errands such as washing up, laundry, and cleaning my room. I then walked into town to go into a grocery store. After town, I walked to the beach with my flatmate and sat along the beach wall for a while in the sun. When I walked home from the beach, I made some food at home as an early dinner/ afternoon snack, and then took them off for the evening.

8. How did the garment feel when you were sitting?

When sitting, I was slightly more aware of the pads, because they would ride up slightly according to the natural positioning of my legs as I was sitting, with the bottom of the pad resting on the chair and the top of the pads resting closer up, close to my hip bones.

9. How did the garment feel when you were standing or walking?

The garment was more comfortable when standing up than sitting, in my opinion. I often would almost forget I was wearing it while standing/walking, but a few times had to readjust the pads when they rode up too much on my hips/waist from a long distance of walking.	
10. Did you have to adjust the pad position throughout the day? If so,	
a) Why? What were you doing that caused the pads to move? (List more than one reason if necessary)	I did have to adjust the position of the pads a few times throughout the day. This mainly happened when I was switching positions of my body, such as going from sitting to standing, or bending over to standing. They also needed to be adjusted when I used the bathroom, as I moved them up so as not to get them dirty, then had to re-place them when I stood up. The final thing that required repositioning of the pads was a long amount/ distance of walking, but this was less often that they needed to be rearranged.
b) How often did you have to do this? (List number of times per reason)	10-15 times throughout the day, most likely.
11. Any other observations or unanticipated experience wearing the garment through the day?	
The main discomfort while wearing the garment, again like I mentioned above, was mainy psychological. Although it was not noticed throughout the day (at least that I knew of), I was still wondering in the back of my mind if people were noticing/ thinking I looked different for some reason.	
Taking the garment off: Thanks so much for evaluating hipwear today. Take the garment off when you're ready for bed. Place the garment back into the plastic bag provided and return it at the focus group.	
12. How did it feel taking the garment off?	
It was quick and easy to take off, the only thing I wonder is if all elderly people would have the mobility to fully lift their arms above their heads, and it might be helpful to somehow make it an option to pull them down and step out of them as well, in case that is easier for some.	
13. How easy or difficult was it to take the garment off?	
It was easier to take off then it was to put on, because I did not have to worry at that point about the positioning of the pads.	
14. Any other observations or unanticipated experience taking the garment off?	
To limit the amount it rises up / ease of experience for elderly people, it may be helpful to have it be almost more of a bodysuit situation, whether like a leotard or with short bottoms, then with something like Velcro on the straps or snaps on the bottom of the leotard. This may be helpful because then they will be easier to put on, as well, as the pads will not ride up.	
Final evaluation: Please provide your overall impression of hipwear.	

15. Overall, how would you evaluate your experience with the garment today?
1 = least, 5 = most. Highlight your choice below:

a) Comfort

1	2	3	4	5

Explain your choice here:

The garment is actually quite comfortable to wear. The material is soft and does not make you too hot, and also allows for physical activity without chafing because it is an athletic-y material. The reason I did not give it a 5 is again because psychologically they are not as comfortable to use, but for physical comfort it is nice. The pads are boxy, but they are not the final version.

b) Ease-of-use

1	2	3	4	5

Explain your choice here:

They are very straightforward to use, and don't require any specific level of comprehension to figure out how. It is clear just from looking at the garment how it works, and is not overly complicated.

c) Appearance

1	2	3	4	5

Explain your choice here:

The pads of the garment were quite boxy and large, making them more obvious to see than if they had been more tapered down to the leg and thickest in the middle (which I think is the plan for the actual pads, anyways).

16. Any other observations or comments that would be useful for further design development?

NA

Hipwear prototype evaluation form – Participant 2

Before taking part in the evaluation, please carefully read through the questions below. Where possible, complete each section 'in the moment'. If necessary, use a notebook or voice notes to record your observations to complete the form later.

Participant name:	**Date of evaluation:**	**Time garment put on:**	**Time garment taken off:**
[participant 2]	11 / 05 / 2023	7:45 AM	1:57 AM

Putting the garment on: Place under your normal clothes. Make sure pads are positioned over your hip bones. Pads and lower part of the garment should be tucked into your clothing and not visible.
1. How did it feel putting the garment on?
Fine. It was stretchy so it wrapped around me fine. If someone was week or vulnerable in other ways, it might be harder for them.
2. How easy or difficult was it to put the garment on?
Pretty easy. Not hard, but I am 22 years old and very very strong. The garment is very stretchy in a hard way.
3. How did the garment feel once it was on?
The garment feels very figure-hugging and tends to stay in place very well. It's like shrink-wrapped around my body. I feel my body better. And it gives me extra tensegrity.
4. Did wearing the garment influence the choice of clothing you wore over the top? If so, how?
I did "ummm" and "arrrrr" over the fact that the extra padding on the side of my hips will bulge out of my trousers. I went to my wardrobe and tried selecting a more suitable pair of trousers. Ones that wouldn't accentuate the fact that I am wearing padding. But I still went for my first choice anyway which were the woolly marine felted trousers that make me look like I walked out of a period drama. The padding only just shows.
5. Any other observations or unanticipated experience putting the garment on?
Well. If you are commando underneath your trousers. Then you do feel the sticky rubbery place holders on your hips. I didn't realise how large the pads where. I was scared to walk around for a day with them, and felt like people would look at me funny. But none of my housemates have noticed the fact that my hind quarters look slightly more angular. All good.

Participant photo:

6. Add a photo of yourself fully dressed for the day with the garment hidden under your clothes. Use your phone and a mirror to capture your shoulders to knees.

Wearing through the day:
Keep on for the whole day if possible. Be aware if the pads move and are no longer over your hip bones.

7. Describe your day; what activities have you done?

I had breakfast and then went to the university to work on the final design report for SPD230, which involved sitting in front of a computer all day. I was getting up to go to the toilet and get water. From around 13:30, I went back home to cook lunch which involved me shopping in town: climbing up and down Jacobs ladder. I then went to Penryn campus by bicycle to catch a few minutes of the Cultural immersion check-in social with the team, which I had to leave early, to go and see my friend's final year performance at AMATA. After that I rode home and cooked dinner with my house mates. We sat outside on the decking to eat it. Light rain was falling. I then continued up to my bedroom to finish off the report.

8. How did the garment feel when you were sitting?

It felt fine. The pads didn't feel like they were digging into me, or being pushed up back into the garment as I sat. You rarely noticed them. I usually forgot that I was wearing it at all.

9. How did the garment feel when you were standing or walking?

It felt very figure-hugging. It made me want to stand proud. It made me feel very muscular. It was tight, but not too tight. I could breathe comfortably. I didn't have any problems bending over or moving and twisting my body without the garment slipping around.

10. Did you have to adjust the pad position throughout the day? If so,

a) Why? What were you doing that caused the	I put some pants on. Because the feeling of those rubber grips where too cringey against my bare skin. The pads were moving

pads to move? (List more than one reason if necessary)	throughout the day, and eventually turned into bottom protectors instead of hip protectors. A slight migration in the positioning meant my hip was only covered by a small corner of the pad. This slippage probably occurred due to my activities during the day: Walking, Standing, Sitting, Cycling, Running down Jacobs ladder, Etc... I didn't even bother to adjust them, because I was mostly in public spaces, and I didn't feel like undoing my trousers in front of others. I tried to adjust them by shuffling the garment around under my trousers but to no prevail. The sticky plastic rubber grips were too effective.
b) How often did you have to do this? (List number of times per reason)	I tried it at various amounts throughout the evening.

11. Any other observations or unanticipated experiences wearing the garment throughout the day?

The slippery garment encouraged my thermal underlayer to bunch up over the waist height of my trousers. Something which I found annoying. The garment was very effective at containing heat. It doesn't make it ideal for cycling places at great speed.

Taking the garment off:
Thanks so much for evaluating hipwear today. Take the garment off when you're ready for bed. Place the garment back into the plastic bag provided and return it at the focus group.

12. How did it feel taking the garment off?

The garment was harder to get off than usual, only because of its stretchy composure. This made it stretch awkwardly along my body with resistance, like a training yoga band or something. But it wasn't too bad.

13. How easy or difficult was it to take the garment off?

Fairly easy for a 22-year-old male. I did have trouble with its stretchiness. It took more effort for sure.

14. Any other observations or unanticipated experiences taking the garment off?

The rubber grips where the pads are based tended to grip onto other clothing whilst I was trying to pull it off.

Final evaluation:
Please provide your overall impression of hipwear.

15. Overall, how would you evaluate your experience with the garment today?
1 = least, 5 = most. Highlight your choice below:

a) Comfort

1	2	3	4	5

Explain your choice here:

There was no discomfort. Only that of others opinions about me and whether or not they could see it. Although I forgot about the pads throughout the day, I did notice sitting on them sometimes, or having to readjust them .

b) Ease-of-use				
1	2	3	4	5
Explain your choice here:				
Pretty easy to put the garment on and off. Once its on, its on, and you only have to adjust it sometimes throughout the day.				
c) Appearance				
1	2	3	4	5
Explain your choice here:				
I was a bit afraid of their appearance and constantly wondered whether or not anyone noticed them. I was wearing very tight-fitting trousers, so the pads did make an outline on my bum area. All in all, I loved the sleek black gloss to the garment, the way its made makes me feel and look strong.				
16. Any other observations or comments that would be useful for further design development?				
Something about pulling the garment on and off. I feel as though older person or more vulnerable people might struggle a bit if they have fatigue or weakness.				

Hipwear prototype evaluation form – Participant 3

Before taking part in the evaluation, please carefully read through the questions below. Where possible, complete each section 'in the moment'. If necessary, use a notebook or voice notes to record your observations to complete the form later.

Participant name:	**Date of evaluation:**	**Time garment put on:**	**Time garment taken off:**
[Participant 3]	10 / 05 / 2023	07:20 AM	8:00 PM

Putting the garment on:
Place under your normal clothes. Make sure pads are positioned over your hip bones. Pads and lower part of the garment should be tucked into your clothing and not visible.

1. How did it feel putting the garment on?

A little awkward pulling it on over the head (and slightly claustrophobic) due to the position of the pads. The stretch and softness of the vest did aid in the ease of dressing, but the pads slightly took away from that.

2. How easy or difficult was it to put the garment on?

It was made a little difficult due to the pads being in-situ - potentially placing them into the garment once its on the body would be easier, especially for those with limited dexterity who might struggle pulling the pads down over the head and shoulders.

3. How did the garment feel once it was on?

The pads instantly felt quite warm against the hips - not an issue and it gave a feeling of protection, but I was conscious that they were there.

4. Did wearing the garment influence the choice of clothing you wore over the top? If so, how?

It definitely took me longer to dress and to decide what to wear. I opted for a longer jumper with the reasoning that it would cover/prevent any potential visibility of the pads.

5. Any other observations or unanticipated experience putting the garment on?

Participant photo:

6. Add a photo of yourself fully dressed for the day with the garment hidden under your clothes. Use your phone and a mirror to capture your shoulders to knees.

Wearing through the day:
Keep on for the whole day if possible. Be aware if the pads move and are no longer over your hip bones.

7. Describe your day; what activities have you done?	
Walk at the beach; cleaned & vacuumed bedroom; walked through town; work at university	
8. How did the garment feel when you were sitting?	
Fine - the pads wrapped around my hips so it felt as if I was sat on the bottom edges of them, but this wasn't uncomfortable.	
9. How did the garment feel when you were standing or walking?	
Comfortable, but I was conscious of the pads being there.	
10. Did you have to adjust the pad position throughout the day? If so,	
a) Why? What were you doing that caused the pads to move? (List more than one reason if necessary)	Possibly subconsciously it felt as if the left pad wasn't positioned correctly over the hip so re-positioning was to try to rectify this. I keep my phone in my back left pocket so this could have been the cause.
b) How often did you have to do this? (List	Once or twice after each time using the loo

number of times per reason)	

11. Any other observations or unanticipated experience wearing the garment through the day?

Slightly difficult to get items into and out of trouser pockets; took longer than normal to 're-dress' after using the toilet; re-positioning the pads wasn't something I felt particularly comfortable or able to do in public, opting to do it in the bathroom/an empty room; the garment felt as if it was bunching a little against by lower back - possibly due to wearing a belt?; bending down to tie laces etc. there was a bit of resistance from the pads, but nothing major; my left hip bone got a bit itchy during the afternoon where the pad was moving a little as I walked (nothing major though).

Taking the garment off:

Thanks so much for evaluating hipwear today. Take the garment off when you're ready for bed. Place the garment back into the plastic bag provided and return it at the focus group.

12. How did it feel taking the garment off?

It felt nice to be free of the pads. Again, the material of the garment helped it to slide off easily and comfortably.

13. How easy or difficult was it to take the garment off?

I'd say it was easier than putting it on, but still required a bit more thought than a 'normal' garment. I ended up pulling upwards from the under the arms, where I'd normally pull the hem.

14. Any other observations or unanticipated experience taking the garment off?

Final evaluation:

Please provide your overall impression of hipwear.

15. Overall, how would you evaluate your experience with the garment today?
1 = least, 5 = most. Highlight your choice below:

a) Comfort

1	2	3	4	5

Explain your choice here:

I was conscious of wearing the garment throughout the day and found the sensation of having something against my hips slightly foreign

b) Ease-of-use

1	2	3	4	5

Explain your choice here:

The garment required a bit more thought and adjustment to put on and wear throughout the day than a normal garment would. It might take a little getting used to, but I don't think it would be an issue for the user

c) Appearance

1	2	3	4	5

Explain your choice here:

I wasn't at all concerned about how the actual garment looked - overall I would say it is discreet and has a sporty appearance which doesn't stigmatise or look at all 'medical'. The only thing I

would say is that I was conscious of other people being able to tell that I was wearing the pads due to my hips looking wider or bulky.
16. Any other observations or comments that would be useful for further design development?
Personally I would have found it easier to insert the pads once the garment was on, so supplying the vest and pads separately in the packaging might be better?

Hipwear prototype evaluation form – Participant 4

Before taking part in the evaluation, please carefully read through the questions below. Where possible, complete each section 'in the moment'. If necessary, use a notebook or voice notes to record your observations to complete the form later.

Participant name:	**Date of evaluation:**	**Time garment put on:**	**Time garment taken off:**
[Participant 4]	15 /5/ 2023	08:00 AM	09:00 PM

Putting the garment on:
Place under your normal clothes. Make sure pads are positioned over your hip bones. Pads and lower part of the garment should be tucked into your clothing and not visible.

1. How did it feel putting the garment on?

I was unsure which way the garment went on. But fits nicely when finally on. When putting on trousers, pads are moved around quite a lot. Using a belt slightly inhibits where the pads fall if it's on tight.

2. How easy or difficult was it to put the garment on?

Quite easy, same as putting on a sports shirt.

3. How did the garment feel once it was on?

Good, on its own, it feels fitted on each part of the body.

4. Did wearing the garment influence the choice of clothing you wore over the top? If so, how?

I am wearing a belt to support my shorts; im unsure at this time if it will change anything drastically, but at first glance, it does move the pads, so I will see if I need to change during the day.

5. Any other observations or unanticipated experience putting the garment on?

I have a clavicle injury, and sometimes tighter clothing can irritate it. However, the fabric seems stretchy enough not to scratch it.

Participant photo:

6. Add a photo of yourself fully dressed for the day with the garment hidden under your clothes. Use your phone and a mirror to capture your shoulders to knees.

Wearing through the day:
Keep on for the whole day if possible. Be aware if the pads move and are no longer over your hip bones.

7. Describe your day; what activities have you done?	
I walked to uni, worked at the computer (sitting), went for a walk, walked home, made lunch, worked from home (sitting and standing), went for a run, and removed the garment.	
8. How did the garment feel when you were sitting?	
Good, a bit itchy in some parts of the back, in certain positions. Wearing a belt and trousers has moved the pads, but it feels very comfortable, so I don't notice until I start walking.	
9. How did the garment feel when you were standing or walking?	
Very good didn't really notice it.	
10. Did you have to adjust the pad position throughout the day? If so,	
a) Why? What were you doing that caused the pads to move? (List more than one reason if necessary)	From sitting to standing, the change in body position moved them.
b) How often did you have to do this? (List number of times per reason)	Every time I got up (if I noticed it, as I would often get up, move around, not see it had moved and then put my hands in my pockets and realise and adjust them).
11. Any other observations or unanticipated experience wearing the garment through the day?	

I had to run somewhere at a point in the day, and it didn't feel very breathable; it trapped the sweat on my upper body. It did hinder using my pockets a bit, but it was more about getting used to having a 'thing' there.

Taking the garment off:
Thanks so much for evaluating hipwear today. Take the garment off when you're ready for bed. Place the garment back into the plastic bag provided and return it at the focus group.

12. How did it feel taking the garment off?

Very easy, kind of relieving.

13. How easy or difficult was it to take the garment off?

Very easy no problems.

14. Any other observations or unanticipated experience taking the garment off?

No.

Final evaluation:
Please provide your overall impression of hipwear.

15. Overall, how would you evaluate your experience with the garment today?
1 = least, 5 = most. Highlight your choice below:

a) Comfort

1	2	3	4	5

Explain your choice here:

Very easy to use, not noticeable on my body, almost to a fault to where I didn't notice the pads moving off my hips.

b) Ease-of-use

1	2	3	4	5

Explain your choice here:

Easy to put on and off.

c) Appearance

1	2	3	4	5

Explain your choice here:

Could do with some visual stimuli for the inside and outside, so I know if im putting it on inside out or back to front.

16. Any other observations or comments that would be useful for further design development?