DESIGNING OF HIP PROTECTORS FOR

ELDERLY WOMEN

By

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Title of Study: DESIGNING OF HIP PROTECTORS FOR ELDERLY WOMEN

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Abstract: Wearing a hip protector is a method to prevent hip fracture. However, low adherence to wearing a hip protector is one of the major reasons of its low efficacy. Low adherence is associated with design problems of existing hip protectors. Therefore, the purpose of the study was twofold, first, to develop a hip protector prototype that addresses existing design problems, second to evaluate the developed prototype in terms of user acceptance. A review of literature, market research and an analysis of focus group interviews helped to determine design criteria that were integrated into the prototype to address existing design problems. The developed prototype was evaluated in three phases: phase 01 – conducted in a laboratory, phase 02 – overnight wear test and phase 03 – individual interview, where subjects provided their perceptions about different aspects of the hip protector prototype. One sample t-test, paired sample t-test and ANOVA were employed to analyze quantitative perceptual data. Qualitative data were analyzed using the framework approach. Analysis showed that all subjects had high positive perceptions about different aspects of the hip protector prototype. Subjects' high positive perceptions did not change significantly after overnight wear test. Subjects also considered the hip protector prototype completely nonrestrictive in terms of mobility. To get deeper insights into subjects' perceptions, future research suggestions are also offered in the conclusion section of this study.

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CHAPTER I

INTRODUCTION

Falling is one of the most serious problems today, primarily because falls lead to unintended fatal and non-fatal injuries. Falls cause significant pain and suffering to fallers, make them dependent on others and pose a large economic burden to both families and societies. In general, elderly people aged 65 years and over are more prone to falls because of the deterioration of their muscle strength, bone density and balance (Zhang, 2013). Hence, this study primarily focuses on designing of hip protectors, a protective undergarment to prevent hip fracture during falls, for elderly people.

The World Health Organization (2015) defined unintentional resting on the ground from an elevated place as a fall and denoted it to be the second leading cause of death. One out of three adults aged 65 years and over experiences falls every year (Center for Diseases Control and Prevention, 2015). Falls increase the risk of early death and in 2011 were responsible for the death of 22,900 older adults (CDC, 2015). In addition, 20% to 30% of all falls cause moderate to severe injuries and 95% of all hip fractures are results of falls (CDC, 2015).

Hip fracture has been considered to be one of the major public health problems among elderly people for many years (Grisso et al., 1991), and in the United States alone, it accounts for 350,000 hospital admissions and 60,000 nursing home admissions each year (American Academy of Orthopedic Surgeons, 2015). Furthermore, within a year of hospitalization, 24% of hip fracture patients die and half of the hip fracture patients lose the ability to walk (AAOS, 2016). In 2002, incidences of hip fracture cost the US economy more than $17 billion and in 2013, rose to $34 billion (CDC, 2015). The cumulative expenses of falls in the US are estimated to exceed $474 billion in the next 20 years (AAOS, 2016). Hip fracture incidences not only cause monetary burden but also increase the disability rate among elderly people and make them functionally impaired and care dependent (Empana, Dargent-Molina, Bréart, & for the, 2004). Kuntz, Gee, Ahn, and Mehta (2011) reported that, in the United States, every year at least 329,000 people sustain hip fractures and of them 80% are women. Studies have also proven that with the increase of age, the hip fracture rate also increases, and appallingly it rises 10 to 15 times more in the people aged 85 years and over when compared to the people aged 60 to 65 years (Kuntz et al., 2011).

In 2012, the World Health Organization (2014) reported the life expectancy of males and females of the United States to be 75 years and 81 years respectively, and overall life expectancy was projected to rise. With the anticipated increase in the elderly population, fall-prone individuals in the population will naturally increase (AAOS, 2016). In addition, most Americans prefer to age in a homelike familiar environment and to live individually as long as possible (Schwarz & Brent, 1999). Hence, the elderly population will be exposed to a higher risk of falls and hip fractures for prolonged periods due to their extended lifetimes.

Muscles, fat and skin around the hip region work as a natural impact absorber when people fall (Choi, 2013). However, with the increase of age, the strength of muscles around the hip decreases (Choi, 2013). Bone strength and bone density also decrease with age (Choi, 2013; Kuntz et al., 2011). Inadequate strength and density of bones, and weakened muscles make the hip bones of elderly people more susceptible to fracture. This is empirically supported by research done by Laing, Feldman, Jalili, Tsai, and Robinovitch (2011). They also showed that if the impact force is directly transmitted to the hip bone, the possibility of hip fracture increases by 32 fold (Laing et al., 2011). Hence, in recent years, research has heavily focused on developing methods of hip protection and strengthening hip muscles so that transmission of impact energy to the hip bones can be reduced significantly (Deshmukh, 2013). One such method is the use of a hip protector. Hip protectors are designed to minimize the impact force below the threshold that is required to fracture hip bones (Choi, 2013; Deshmukh, 2013; Pekka Kannus & Parkkari, 2006).

Statement of the Problem

The efficacy of hip protectors is a matter of debate, however, in recent studies, the use of a hip protector is recommended as the best practice (Combes & Price, 2014; Santesso, Carrasco-Labra, & Brignardello-Petersen, 2014). Interestingly, studies show that the lack of adherence to wearing hip protectors is one of the major reasons for low efficacy of hip protectors (Combes & Price, 2014; O'Halloran et al., 2007; Santesso et al., 2014). Braun (1998) found that community dwelling elderly people acknowledged the adverse consequences of falls, and understood the need to address fall-related risk factors.

Usually hip protector pads are integrated with undergarments and are worn underneath regular outerwear (Santesso et al., 2014). Hip protectors either dissipate or absorb impact energy during a fall (Deshmukh, 2013). Hence, the efficacy of hip protectors depends both on the effectiveness of the hip protector pads and whether wearers have them on during falls. To date, most studies have heavily focused on increasing the effectiveness of hip protector pads (Deshmukh, 2013; Laing et al., 2011) and on whether hip protectors are effective in different dwelling environments (Kiel et al., 2007; Sawka et al., 2005). Except the study conducted by Chan et al. (2000), no research has measured the relationship between design features of hip protectors and users subjective requirement as the primary outcome variable. In his study, Chan et al. (2000) investigated the effectiveness, perception of comfort and perception of appearance of a newly designed hip protector. Nevertheless, most of the 11 subjects of that study were diagnosed with dementia, casting serious concern about the reliability of the results. To date, little attention has been paid to determine whether and to what extent the existing design features of the hip protectors address wearers' subjective and physiological requirements.

Significance of the Study

The effectiveness of hip protectors depends not only on biomechanical properties that shunt or absorb impact energies but also on design factors that affect users' adherence (Deshmukh, 2013). Hip protectors can only be effective if they are actually worn during falls (O'Halloran et al., 2007). Hence, maximum protection from falling can only be achievable if people will wear hip protectors during their day-to-day activities and overnight.

A good design attracts consumers, communicates with them, and adds value to the product by increasing the perception of quality of the product (Black & Baker, 1987; Bloch, 1995). Design features that meet users' specific requirements are expected to have higher acceptability (Bloch, 1995). Because, the relationship between design features of hip protectors and user requirements have not been researched, it is not evident that their requirements are currently being met. Therefore, the findings of this study provide a significant contribution toward defining design parameters of hip protectors and give better insight into hip protector users' functional needs.

If adherence to wearing hip protectors can be increased, elderly people will feel more independent and secure, thereby enhancing their overall quality of life (Stollenwerk, Waldeyer, Klein-Meding, Müller, & Stock, 2013). Fear of falling makes elderly people limit their activities and in turn decreases the quality of life (Stollenwerk et al., 2013). The secondary effect of using hip protectors is that people who are at high risk of falling feel more secure while wearing them (Koike et al., 2009). However, to increase the adherence rate to wearing hip protectors, user specific requirements need to be addressed. Hence, the findings of this study will help to design highly acceptable hip protectors that do not compromise the utilitarian properties.

With an increase of adherence rate to wearing hip protectors, the incidences of hip fracture can be reduced (Deshmukh, 2013). Lower incidences of hip fracture will alleviate direct and indirect medical costs, caregiver burdens, the familial burden of taking care of injured patients and may help people live longer. Hence, the findings of the study may not only improve adherence to wearing hip protectors but also reduce the social and economic burden of fall related injuries, enabling elderly people to age in place.

Purpose of the Study

Pekka Kannus and Parkkari (2006) suggested that all protective methods should be applied to prevent hip fracture. Wearing a hip protector is one of the best practices to prevent hip fracture incidences (Santesso et al., 2014). However, low adherence to wearing hip protectors is one of the major barriers for their efficacy (Combes & Price, 2014; Deshmukh, 2013; O'Halloran et al., 2007; Santesso et al., 2014). To improve the adherence rate to wearing hip protectors, different design aspects of the hip protectors that affect user perception need to be investigated (Hubacher & Wettstein, 2001; Samelson, Zhang, Felson, Kiel, & Hannan, 2002). Furthermore, there is a need to determine the extent to which the existing design features of hip protectors fulfill users' subjective requirements related to their activities. Hence, this study is concerned with gaining comprehensive insight into the design features that combine the functional elements of the hip protector (Lamb & Kallal, 1992). Therefore, the purpose of the study has two parts. First, to develop a hip protector prototype that addresses existing design problems of hip protectors. And, to evaluate the prototype to determine how well the developed prototype addresses the problems. The purpose of the study led to the following specific objectives:

1. To refine and rank the design criteria which are identified based on elderly peoples' functional and aesthetic needs and their day-to-day activities.

2. To design and develop a hip protector prototype integrating the design criteria.

3. To conduct wear tests to determine how well the prototype fulfills users' subjective requirements.

CHAPTER II

BACKGROUND

The purpose of the study is to develop a hip protector prototype integrating the design criteria that were identified based on users' subjective requirements and subsequently evaluate the developed prototype by conducting wear tests. The background chapter will explore information related to variables of interest. The first section will provide information related to hip anatomy, methods to prevent hip fracture, efficacy and adherence to wearing hip protectors. The subsequent section will provide detailed information about market analysis that was conducted to explore how manufacturers address users' requirements. This section will be followed by results from a preliminary study that was conducted to get insight into elderly women's clothing behavior. The background chapter will also highlight the theory that drove the current study. Finally, the design criteria, developed from the background research, are described and the study research questions are outlined.

Review of Literature

An unintended resting of a person on the ground or the floor or other lower level from an elevated or standing position is defined as a fall (World Health Organization, 2015). In 2002, the World Health Organization (WHO) published a report which showed 391,000 people globally died because of inadvertent falls, thereby making falls the 2nd leading cause of inadvertent injury death only after road traffic injuries (WHO, 2015). The severity of fall-related injuries became more evident when the CDC (2015) reported that due to fall related injuries, every 17 seconds an elderly person was hospitalized for emergency treatment and every 30 minutes an older adult died. Some of the health impairments falls cause are head traumas, hip fractures, loss of mobility etc. Falls often lead to hospital admission. In addition, fear of falling makes people limit their activity and leads to a reduction in quality of life (CDC, 2014). Global consequences of falls summarized by Yoshida (2007) are shown in the Figure 2.1. This report outlined the estimated percentage of consequences resulted from falls globally.

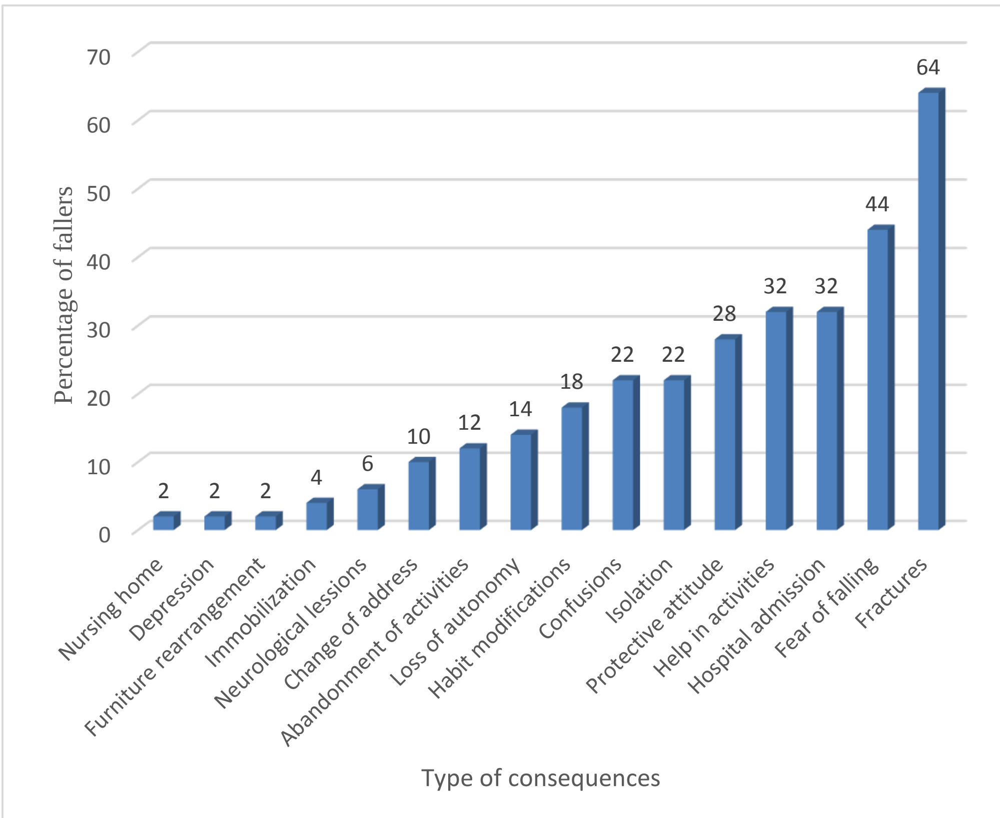

Figure 2.1. Consequences of falls. Adapted from "A global report on falls prevention: epidemiology of falls" by Yoshida, S., 2007, *World Health Organization*.

This global report showed that 64% of all fallers experienced bone fractures, 44% experienced the development of fear of falling, 32% admitted to hospitals and needed help with daily activities, 28% developed protective attitudes and so on. It is interesting to note that, the percentage of fallers admitted to nursing homes is significantly lower than other types of fall-consequences because of the inadequate number of nursing home facilities in the developing and underdeveloped countries (Yoshida, 2007).

The economic burden of fall related injuries is even more alarming. Direct medical costs of falls among older adults in the United States exceeded $30 billion in 2012 alone (CDC, 2014). Furthermore, in 2002, each faller used $12,000 of additional health care resources when compared to a non-faller (Lawrence et al., 2009).

Grisso et al. (1991) showed that more than 90% of falls lead to hip fracture and 90% of those who experience hip fracture are over 70 years old. As people age, both falls and the implication of falls become more complex (Pekka Kannus & Parkkari, 2006). In addition, the hip fracture rate is more than 10 to 15 times more for the people aged 85 years and over when compared to the people of 60 to 65 years (Kuntz et al., 2011). In 2015, 47.8 million people in the United States were 65 years and over, and it is estimated that the number of people aged 65 and over will grow to 98.1 million by 2060. Of those, the most rapidly growing population will be people 85 years and over, who will double by 2035 and quadruple by 2060 (United States Census Bureau, 2015). This rapid increase in the elderly population of the United States will lead to the rise of yearly hip fracture rate from 329,000 in 2011 to 500,000 in 2040 (Kuntz et al., 2011). Furthermore, the CDC (2013) reported unintentional falls as the leading cause of death for the population aged 65 years and over and the third most common cause of death overall. (Figure 2.2).

	Age Groups									
Rank	**< 1**	**1 to 4**	**5 to 9**	**10 to 14**	**15 to 24**	**25 to 34**	**35 to 44**	**45 to 54**	**55 to 64**	**65+**
1	UN SF 979	UN DR 393	UN MV 342	UN MV 414	UN MV 6,510	UN PN 8,251	UN PN 8,374	UN PN 10,651	UN PN 6,388	UN Fall 25,464
2	Homicide Unspecified 139	UN MV 327	UN DR 116	Suicide SF 231	Homicide FA 3,704	UN MV 5,776	UN MV 4,448	UN MV 5,082	UN MV 4,502	UN MV 6,333
3	Homicide Unspecified 74	UN SF 161	UN Fire/Burn 87	Suicide FA 137	UN PN 3,293	Homicide FA 3,372	Suicide FA 2,948	Suicide FA 4,057	Suicide FA 3,809	Suicide FA 5,113
4	UN MV 66	Homicide Unspecified 153	Homicide FA 48	Homicide FA 94	Suicide FA 2,210	Suicide FA 2,897	Suicide SF 1,868	Suicide SF 2,007	UN Fall 2,283	UN Unspecified 4,316
5	UN SF 43	UN Fire/Burn 129	UN SF 44	UN DR 93	Suicide SF 1,839	Suicide SF 2,154	Homicide FA 1,843	Suicide PN 1,867	Suicide PN 1,528	UN SF 3,616

UN = Unintentional, SF = Suffocation, DR = Drowning, PN = Poisoning, FA = Firearm, MV = Motor Vehicle Traffic

Figure 2.2. Five leading causes of injury death by age group in the US in 2013. Adapted from "Injury prevention and control: Data and statistics" March 31, 2015, *Center for Disease Control and Prevention Center*.

Hip Anatomy

Stability of the hip is extremely important so that humans can perform normal activities (Davies, Davies, & Gray, 1962). The hip, along with the muscles surrounding the hip region, provides a wide range of motion while keeping the body stable and upright (Davies et al., 1962). However, misalignment of the hip joint, hip fracture or sprain can lead to chronic pain, limitation of movement or even disability (Davies et al., 1962). Knowing hip anatomy will help designers understand what needs to be considered for designing hip protectors that ensure the range of motion as well as provide protection.

The hip has a ball and socket joint that consists of the spherical head, or ball, of the femur bone that fits into the depression of the acetabulum, or socket, of the hipbone, as depicted in Figure 2.3. This creates a polyaxial joint which permits movement around three axes (Tortora & Nielsen, 2009). The femur, or thighbone, is the longest and strongest bone of the human body and its upper, or proximal, end creates the ball of the hip joint while the lower, or distal, end forms the knee joint. The upper end of the femur consists of a head, a neck, a greater, and a lesser trochanter (Davies et al., 1962). The rounded head has a centered pit, which is called the fovea (Davies et al., 1962). Ligaments connect the fovea to the acetabulum of the hipbones (Davies et al., 1962). The femur neck forms an angle between the head and the shaft (Figure 2.3). Because of the ligaments, the rim of the acetabulum that holds the head of the femur, and the muscles surrounding the joint, the hip joint is extremely stable (Davies et al., 1962).

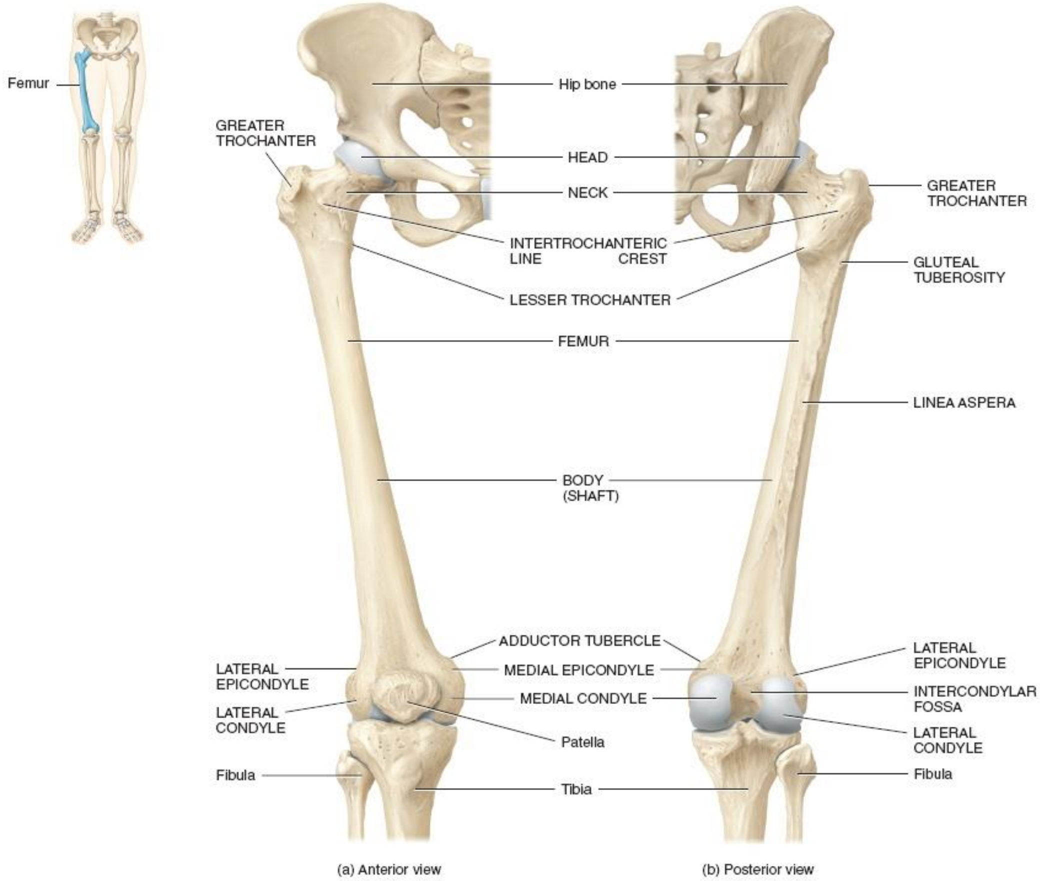

Figure 2.3. Right femur in relation to the hip bone. Adapted from "The Skeletal System: The Appendicular Skeleton," by Tortora, G. J., & Nielsen, M. T., 2009, *Principles of human anatomy* (pp. 219). Hoboken, NJ: J. Wiley.

Typically, two types of fracture: (Figure 2.4) femoral neck fracture – when neck of femur gets fractured, and intertrochanteric fracture – when the region between the greater and lesser trochanter get fractured, occur around the hip region (Deshmukh, 2013).

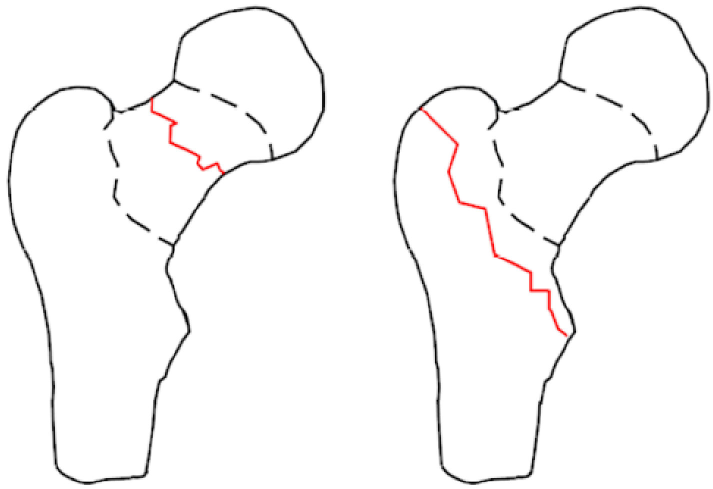

Figure 2.4. Types of hip fracture: Femoral neck fracture (left) and intertrochanteric fracture (right). Adapted from "*Effect of product design characteristics on biomechanical performance and user preferences in the selection of wearable hip protectors*," by Deshmukh, P. M., 2013, (Unpublished master's thesis). Simon Fraser University, Canada.

Methods to Prevent Hip Fracture

Most hip fractures occur as a result of falls and most falls occur at fallers' place of residence (AAOS, 2016). The concern regarding the alarming rate of hip fracture among the elderly population has led to the innovation and modification of materials and methods to prevent hip fracture (Choi, 2013; Deshmukh, 2013). There are three methods to prevent hip fracture – exercise, compliant floor and use of hip protectors.

Exercise. Possible ways to reduce the hip fracture rate are to prevent fallers from falling, increase strength of the bones and muscles, or lessen impact forces below the minimum level that is required to break hip bones. Because exercise can increase muscle strength and improve balance, it can reduce the number of falls as well as the risk of falling among elderly people (Arnold, Sran, & Harrison, 2008).

The martial art (MA) training program is considered as one of the most effective exercise programs to prevent hip fractures (Weerdesteyn, Groen, van Swigchem, & Duysens, 2008). Weerdesteyn et al. (2008) stated that the MA technique improves fallers' reaction time and helps fallers to change their fall into a rolling movement. Because of the rolling movement, impact forces are converted into kinetic energy and distributed over a larger area, and as a result the impact forces transmitted to the hip joint are reduced. In addition, the MA technique also teaches how to stretch out arms to protect the head and break the fall (Weerdesteyn et al., 2008). Furthermore, in support of the last statement, Groen, Weerdesteyn, and Duysens (2007) showed that the MA technique reduced impact velocity and it also reduced the ultimate impact forces on the hips by 27.5% to 30%.

Compliant floor. Another existing method to decrease the peak impact force is to make the floor more energy absorbent. This method is called compliant floor or safety floor (Bhan, Levine, & Laing, 2014). If the flooring material can absorb a substantial amount of impact energy without affecting the mobility of the inhabitants, the incidences of hip fracture can be reduced (Bhan et al., 2014). Li, Tsushima, and Tsushima (2013) conducted a study in Japan, and compared the force attenuation properties of hip protectors on different flooring materials: concrete, wood and Tatami matting, a traditional Japanese flooring method constructed from rice straw. They concluded that Tatami matting reduced the impact force more than concrete and wood flooring did, and brought down the impact force below the threshold that is required to fracture hip bones. Another study conducted by Bhan et al. (2014) supported the previous assertion that compliant floor reduced peak impact force and acceleration by 20.7% to 28.3%. Because compliant floor itself works to absorb the force and does not target any specific area of the body, it provides wider protection throughout the whole body, including the head. This passive intervention approach can be very useful in high risk environments such as hospitals, nursing homes and assisted living homes, however, it doesn't provide any protection to ambulant elderly people in outdoor spaces (Li et al., 2013).

Hip protectors. The hip protector is a specially designed undergarment embedded with protective pads on both sides (see Figure 2.5) (Santesso et al., 2014). Upon inspecting numerous hip protectors, certain common properties were observed. Some protective pads were permanently sewn inside the undergarment and some were placed in small pockets with flaps on the lateral aspects of the undergarment. Pads act as barriers between the hip and ground during falls, and protect the greater trochanter from the direct transmission of impact force (Choi, 2013).

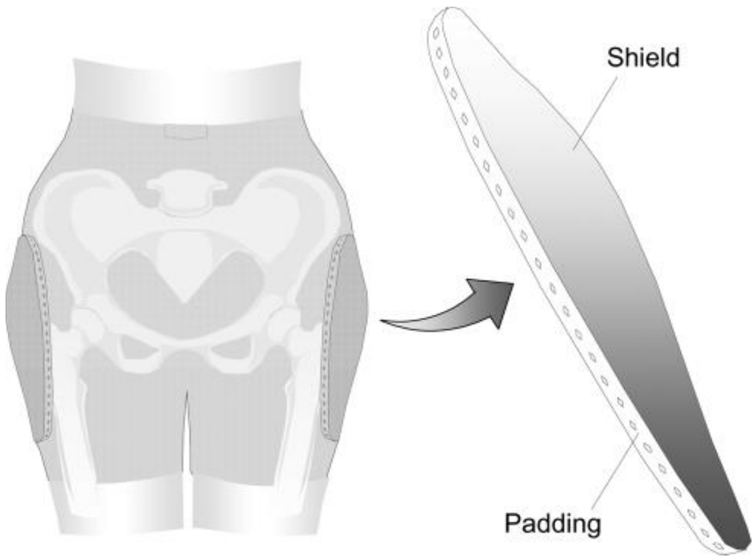

Figure 2.5. Hip protector and position of protector pads. Adapted from "Prevention of hip fracture with hip protectors," by Kannus, P., & Parkkari, J., 2006, *Age and ageing*, *35*(suppl 2), ii51-ii54. doi: 10.1093/ageing/afl087

Protective pads can be categorized into three types: soft pad, hard pad and combination of soft and hard pad (Figure 2.6). Typically, soft pads are made of viscoelastic open cell foams, three dimensional spacer fabric, rubber or silicon. When force is applied, soft pad pads compress and deform, and in doing so absorb energy. This is called an energy absorption mechanism. Because soft pads are flexible, these are considered to fit the contour of the hip region better than the hard pad (Laing & Robinovitch, 2008). On the other hand, hard pads are usually made of rigid or stiff material. Hard pads create bridges that cover the greater trochanter. They deform or compress slightly when forces are applied, rather they distribute the impact forces to wider areas of soft tissues around the hip region (Deshmukh, 2013).

Combining both soft and hard pads has become more popular as this can provide both energy absorbing and energy shunting properties. In the combined pad, a soft pad is attached to the inner side of the pads that comes into close contact with the skin and the hard pad acts as the outer layer. When force is applied to the outer layer of the protector pads, the hard pad shunts the impact energy away from the greater trochanter to a wider area and the soft pad ensures that the edges of the hard pad don’t dig into the hip flesh (Figure 2.6).

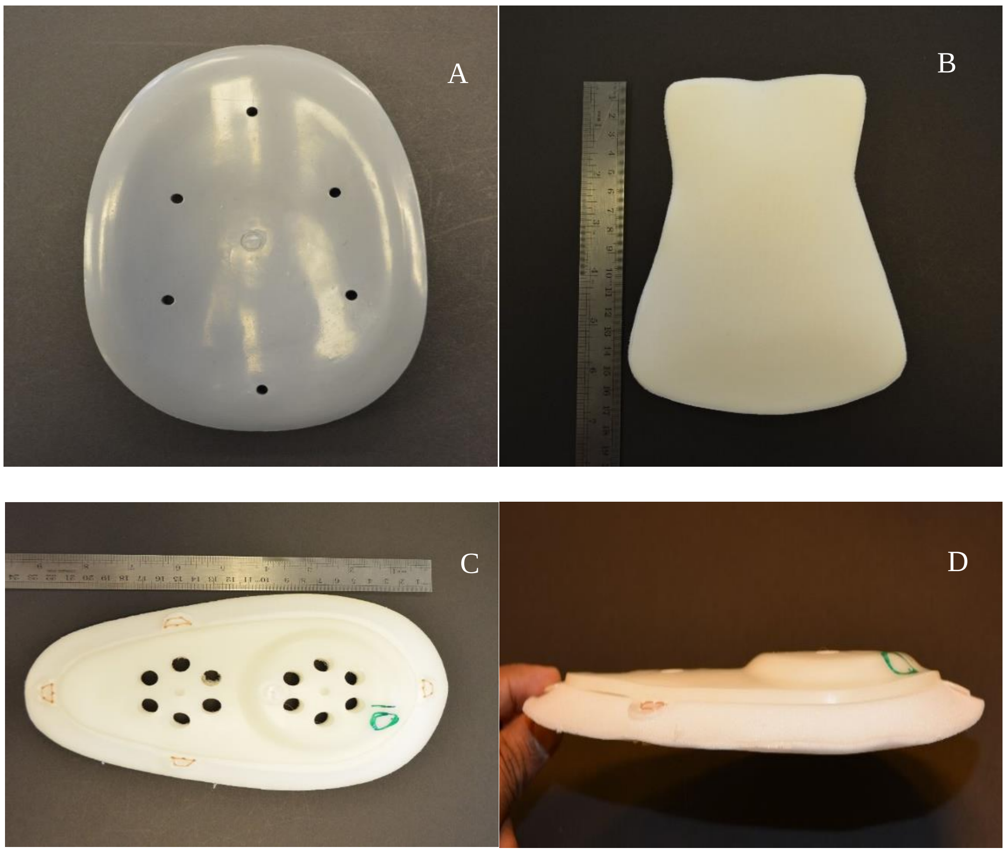

Figure 2.6. Different types of hip protector pads. Top view of a hard-pad (A), top view of a soft-pad (B), top view of a combined pad (C) and side view of a combined pad (D). Photographs were taken during observation of hip protectors.

A novel way of protecting the hip is the inflatable hip protector. This type of hip protector is integrated with pre-impact fall detection sensors (M. N. Nyan, F. E. H. Tay, & E. Murugasu, 2008). Typically the sensors detect a fall few milliseconds prior to the impact and activate the inflation trigger. The airbags then inflate and act as cushioning to absorb the impact energy (M. Nyan, F. E. Tay, & E. Murugasu, 2008). These hip protectors are not visible when they are deflated and once they are inflated, can provide a great extent of energy absorbing capacity. However, the design complexity of the inflatable hip protector made it substantially more expensive than the commercially available hip protectors. Furthermore, the effectiveness and acceptability of inflatable hip protectors among the elderly population have not been tested (Arjmand Boroujeni, 2012).

Efficacy of Hip Protector

Several studies have been conducted to determine the threshold of peak compressive force on the proximal femur of elderly people. Robinovitch et al. (2009) summarized 16 of those studies to provide definitive values of peak compressive force that can be used as a standard for designing hip protectors. In that study, peak compressive force was defined as the maximum force that a human femur can withstand without getting fractured. According to the study, the average value of the peak compressive force was 2,827 N for women and 4,375 N for men, however, the value varied notably when it was compared among people of different ages. The peak compressive force for people of mean age 74 years was 3,770 N and for people of mean age 33 years was 7,550 N (Robinovitch et al., 2009).

Kannus, Parkkari, and Poutala (1999) compared efficacy of four commercial hip protectors and they found that two hip protectors reduced the impact force significantly and were strong enough to prevent hip bones from getting fractured. Figure 2.7 depicts the comparison of force attenuation properties of those four hip protectors. In the figure, vertical bars represent forces after being reduced by the hip protectors, and purple and red horizontal lines represent average value of peak compressive force for males and females respectively. When high force (10,840 N) was applied on all the four hip protectors, KPH1 (combined pad) and KPH2 (combined pad) reduced the impact force to 1360 N and 1170 N which is far below the threshold required to break hip bones. However, Safehip (hard pad) and Safe pants (soft pad) did not provide enough protection. In addition, low (4330 N) and moderate (7230 N) forces were applied to all four hip protectors. Both combined pad hip protectors were found effective for both genders for all ranges of pressure.

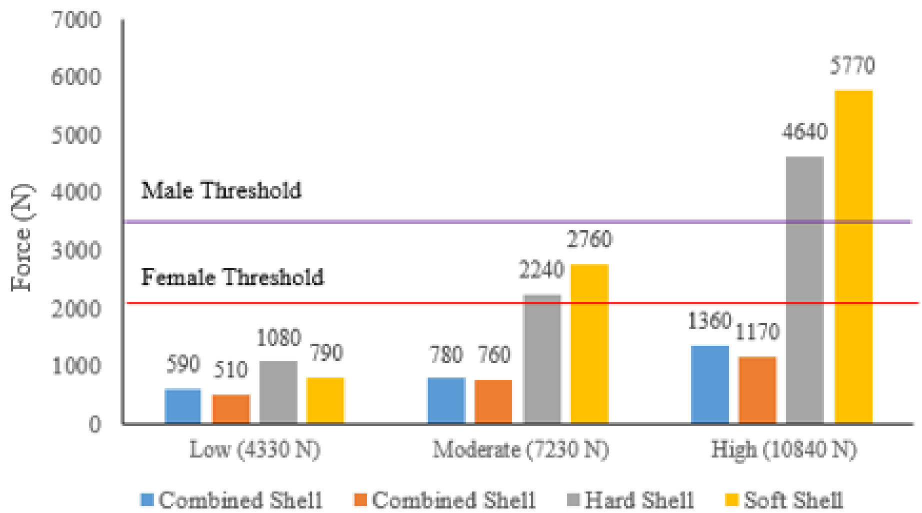

Figure 2.7. Force attenuation properties of four hip protectors. Adapted from "Comparison of force attenuation properties of four different hip protectors under simulated falling conditions in the elderly: an in vitro biomechanical study," by Kannus, P., Parkkari, J., & Poutala, J., 1999, *Bone*, *25*(2), 229-235. doi: 10.1016/S8756-3282(99)00154-4

A study conducted by Pekka Kannus et al. (2000) with 1801 subjects from 22 community based health care centers in Finland compared the hip fracture rate among a hip protector group and a control group. Both energy absorbing and energy shunting hip protectors were used. The study proved that using hip protectors could reduce the risk of hip fracture by 80% among ambulatory elderly people if the fallers would wear hip protectors during falls (Pekka Kannus et al., 2000). In support of the previous assertion, Harada et al. (2001) showed that hip protector wearers experienced significantly less fracture than non-wearers (hip fracture rates 1.2% and 9.7% for wearers and non-wearers respectively). Furthermore, efficacy of hip protectors is more evident among elderly people with fall history and low BMI who have greater risks of hip fracture (Koike et al., 2009).

In the studies prior to 2005, using hip protectors was advocated as an effective strategy to prevent hip fracture, however, some antecedent studies cast doubt on its effectiveness (Parker, Gillespie, & Gillespie, 2006; Sawka et al., 2005). In a systematic review on the effectiveness of hip protectors, Parker et al. (2006) analyzed 14 studies. Out of the 14 studies, three were carried out in residential home settings and 11 in nursing or residential care settings. Analysis of data collected from residential home settings showed no statistically significant relationship between the reduction of hip fracture rate and use of hip protectors. Nevertheless, pooling of data from the rest of the 11 trials supported the effectiveness of hip protectors. Furthermore, no statistically significant evidence was found to relate incidence of pelvic or other fractures with the use of hip protectors (Parker et al., 2006; Van Schoor, Smit, Twisk, Bouter, & Lips, 2003).

Kiel et al. (2007) conducted a randomized control trial in 37 nursing homes in the United States. In the trial, 1,042 nursing home residents were provided with 1-sided energy shunting and energy absorbing hip protectors. Despite overall adherence of 73.8%, the incidence rate of hip fracture of the hip protector group was not significantly different from that of the control group (incidence rate of hip protector group 3.1% vs incident rate of control group 2.5%) (Kiel et al., 2007). However, Kiel et al. (2007) concluded that current designs of hip protectors are not effective in preventing hip fracture among nursing home residents. Likewise, the largest randomized control trial conducted in the United Kingdom challenged the efficacy of hip protectors among independently living women who had high risk factors (Birks et al., 2004). Although these few studies cast doubt on the efficacy of hip protectors, most recent studies advocated use of hip protectors to prevent hip fracture (Combes & Price, 2014; Santesso et al., 2014). In both studies low adherence rate to wearing hip protectors was reported as a prevailing issue (Combes & Price, 2014; Santesso et al., 2014).

Adherence Rate of Hip Protectors

Adherence to wearing hip protectors means wearing hip protectors in accordance with the recommendations of the study protocol, and is measured as the total amount of time hip protectors are worn (Kurrle, Cameron, Quine, & Cumming, 2004). However, in the literature, the adherence rate for hip protectors has very inconsistent and ambiguous definitions (Deshmukh, 2013; Kurrle et al., 2004). In previous studies, the method of defining and reporting adherence rate includes (1) the percentage of days hip protectors were worn during the follow-up of the study, (2) the percentage of hours hip protectors were worn during day time when 12 hours was considered as a baseline, (3) the percentage of hours hip protectors were worn when 24 hours was considered as a base line, (4) the percentage of hours hip protectors were worn considering the waking hours of wearer as base line and (5) percentage of hours hip protectors were worn when wearers were on their feet (Deshmukh, 2013; Kurrle et al., 2004). This wide variety of definitions of the hip protector adherence rate has made the interpretation and extrapolation of the results very difficult (Kurrle et al., 2004).

Adherence rate to wearing hip protectors was measured as a primary or secondary outcome variable in several studies (Chan et al., 2000; Hubacher & Wettstein, 2001; O'Halloran et al., 2007; Parkkari, Heikkilä, & Kannus, 1998; Villar, Hill, Inskip, Thompson, & Cooper, 1998). However, in these studies, the adherence rate fluctuated a great deal. Hubacher and Wettstein (2001) reported that at the beginning of their study 68% of the subjects agreed to wear hip protectors, yet, only 36% of the initial wearers continued to wear hip protectors throughout the whole 10-month study. A review of 36 articles conducted by Van Schoor, Devillé, Bouter, Lips, and Lips (2002) revealed that long term adherence to wearing hip protectors ranged between 20% and 92% (median 56%). Despite the disparity in definition of adherence rate, the majority of research conducted about adherence rate considered a low adherence rate as one of the major factors for low efficacy of hip protectors (Birks et al., 2004; Chan et al., 2000; Combes

& Price, 2014; Deshmukh, 2013; Santesso et al., 2014). Furthermore, Kiel et al. (2007) concluded that hip protectors as currently designed are not effective for preventing hip fracture among nursing home residents.

Inadequacy in design is one of the leading causes for the low adherence rate to wearing hip protectors (Pekka Kannus & Parkkari, 2006). In addition, some determinants were repeatedly mentioned in several studies for lowering the adherence rate among wearers: uncomfortable (too tight or poor fit), ease of don and doff (extra effort and time required), aesthetic and personal appearance, and incompatible with incontinence and physical difficulties (Deshmukh, 2013; Hubacher & Wettstein, 2001; Samelson et al., 2002; Sims-Gould, McKay, Feldman, Scott, & Robinovitch, 2014). Therefore, adherence rate depends not only on the stiffness, softness and shape of the protector pads but also the design aspects of the undergarment wherein the protector pads are embedded (Deshmukh, 2013). Hence, addressing issues related to design features of a hip protector is essential in the quest to increase the user adherence rate.

Market Research

To better understand the design of hip protectors and impact attenuation properties of the hip protector pads, 12 hip protectors were examined. The hip protectors available in the market can be classified into two broad categories: for elderly people and for action sports. Action sport hip protector manufacturers usually produce hip protectors that are suitable for most of the action sports: mountain biking, mountain climbing, sky diving, skiing, snowboarding, skateboarding, roller skating etc. Designs of these hip protectors are customized to ensure mobility to the maximum extent specific to the sport. Most of the action sport hip protectors are made of synthetic fiber for its moisture wicking property, breathability and durability. Furthermore, spandex is incorporated into the fabric to keep the protector pads in their designated place and to make the fabric stretchy and elastic so that it regains its original shape. Two action sport hip protector brands were examined for this study: *Bern Unlimited* and *Demon* (see Figure 2.8). Like most of the action sport hip protectors, these action sport hip protectors were designed to protect not only the thighs and hip bones but also the tail bones. In both of the action sport hip protectors, protector pads were sewn into the synthetic undergarments. In action sport hip protectors, the primary goals are to provide higher protection and wider range of motion.

Figure 2.8. Hip protectors for action sports. (Clockwise, from top left) Front view of Demon hip protector, back view of Demon hip protector, back view of Bern unlimited hip protector and front view of Bern unlimited hip protector. Photographs were taken during observation of hip protectors.

Hip protector pads that are designed specifically for elderly people to prevent hip fractures can be classified into three categories: hard pad, soft pad and combined pad. Combined pad hip protector pads have a hard pad as outer layer to dissipate impact force and a soft pad as inner layer to ensure that edges do not dig into flesh around the hip bone. These hip protectors are designed in such a way that elderly people can wear them 24 hours a day, even to sleep in. To ensure comfort, cotton blended with polyester or nylon and spandex were used. All the available hip protectors were either machine washable or hand washable. However, hip protector pads, which were not machine washable, could be taken off from hip protectors during laundry. Ten different hip protectors were examined closely to gain insight into the design features. Out of 10 hip protectors, 5 were integrated with soft pad protector pads. The rest of the five hip protector pads had combined soft pad and hard pad properties. All the hip protectors examined were intended to be worn as undergarments except for the *Safe hip* open model hip protector and *Jobar Unisex* hip protector. These were made without a crotch to accommodate for incontinence of elderly people, and were intended to be worn over top of underwear. No-crotch hip protectors had adjustable leg openings to fit different sizes and ensure ease of donning and doffing. Manufacturers of all types of hip protectors claimed that their hip protectors were light weight, less bulky than others and not noticeable when worn underneath regular clothes. Table 2.1 provides a summary of the brands, fiber content, method of pad attachment, washability and special features of the ten protectors examined.

Table 2.1

Summary of Hip Protector Undergarments

Brand	Fiber content of the undergarment as reported by the manufacturer	Type of pads	Method of pad attachment	Washability	Special feature
Jobar	65% Polyester and 35% Elastic	Hard	Sewn in	Not provided	No crotch.
FallGard	93% Cotton and 7% Spandex	Combined	Sewn in	Machine washable	n/a
Safehip	71% Cotton, 25% Polyester and 4% Spandex	Combined	Sewn in	Machine washable	No crotch.
Bort Stabilohip	95% Cotton and 5% Spandex	Combined	Side pocket	Machine washable	n/a
Alimed Safehip	71% Cotton, 25% Polyester and 4% Lycra	Hard	Sewn in	Hand or machine washable	n/a
Caresse Grey	95% Cotton and 5% lycra	Combined	Sewn in	Machine washable	n/a
Hydas	100% Cotton	Combined	Side pocket	Machine washable	n/a
DeRoyal	Not provided	Soft	Sewn in	Machine washable	n/a

Gel Bodies	85% Cotton, 10% Lycra and 5% Polyester	Soft	Side pocket	Machine washable	Design is similar to a skirt
Jobar	Nylon-70%, Rubber-20%, Polyurethane-7%, Polyester-3%	No pad	n/a	Hand washable	Covers one thigh.

Preliminary Study

To gain insight into users' subjective requirements related to hip protectors and dressing behavior, women over the age of 65 were interviewed. Focus group interactive interviews were conducted in six counties in the state of Oklahoma by Dr. Ruppert-Stroescu. The researcher analyzed the transcribed interviews using NVivo 10.1 to unfold underlying patterns and themes about elderly people's physiological needs, their concern about clothing fit, comfort and their day-to-day activities which relate to dressing behavior.

For the exploratory data analysis, at first the open coding method was employed to identify summative, essence-capturing and salient attributes and themes that emerged from the textual data. Data were initially coded into themes relating to elderly people' general preferences for outerwear, innerwear and their concern about fall and hip protection. Employing the axial coding principles (Creswell, 2012), the data were further categorized into concern about clothing fit, comfort, size, shape, fiber content, price, and style. Then the relationship between axial coded themes and open coded themes were identified.

A word frequency query was conducted which showed that comfortable, fitting and loose were considered most desirable and most frequently mentioned terms for garments. About the material of the garments, cotton, nylon and blended fiber were repeatedly mentioned.

The selective coding approach (Creswell, 2012) was applied to identify the relationship between the responses of the interviewees and the variables: fit preference, concern for feeling and look, concern for price and concern for size, shape and material. Analysis showed that fit preference, feeling and look were considered important among all the interviewees. When the interviewees were specifically asked about their feeling of wearing a protective garment to protect the lower part of the body, they repeatedly mentioned comfort and the garment being discreet. “Comfort is the key, not too tight”, “Must be comfortable and unnoticeable” etc.

Although most of the interviewees wanted their protective garments to be discreet and less bulky, when the interviewer explained the severe consequences of hip fracture, they responded in favor of protection over look. “Protection is more important over looks”, “Protection is important because with being old looking good is not as important” etc.

Theoretical Perspective

FEA Consumer Needs Model

The theoretical framework adopted for this study is the Functional Expressive Aesthetic (FEA) Consumer Needs Model developed by Lamb and Kallal (1992). At first, it was developed for consumers with special needs, however, all kinds of apparel can be designed based on this theory as it does not distinguish between fashion design and functional design.

The core of the model is the target consumer for whom the apparel is to be designed. To better identify target consumers, demographic, psychographic, physical characteristics, activities and preferences should be taken into consideration. Consumers’ perception and acceptance of apparel is influenced by their culture. They also assess the functionality of the apparel from their cultural stand point. Therefore, designs which do not represent the culture properly might have a low acceptability rate.

The model explains how different elements of the design criteria are intertwined with each other and how their collective features influence consumers' decision making. Basic elements of the design criteria are classified into three categories: functional, aesthetic and expressive.

Functional elements address protection, fit, aid in mobility, comfort, and ease of donning and doffing. The expressive element describes how and whether consumers' values, personality, status, role and self-esteem are properly represented by the design. The aesthetic elements express whether color, texture and pattern can make the design aesthetically pleasing. Consumers may select one category over another depending on the use-situation. However, each design has to meet consumers' minimum subjective requirements of each element with respect to their activities.

In this study, the FEA Consumer Needs Model was employed as a framework to develop the design criteria of the hip protector prototype.

Design Criteria

A review of literature, market research and analysis of focus group interviews helped to identify design problems of existing hip protectors. Because the design problems identified in this study were primarily related to functional aspects and overall look of the hip protector, expressive elements of the hip protector were not investigated.

Desired Features from Preliminary Study

To identify design problems and subsequently determine the desired features of a hip protector, focus group interactive interview data were analyzed. Qualitative data analysis revealed that elderly people wanted the hip protector to be comfortable, to be less bulky, to be discreet if the garment was worn underneath regular clothing, to be washable, should not restrict movement, should not dig into the flesh, should not bunch up in the crotch, should not be itchy and easy to put on and take off. Furthermore, few interviewees showed positive perception about an adjustable hip protector.

Desired Features from Literature Review and Market Research

Several studies conducted to determine the adherence to wearing hip protectors reported some determinants which were responsible for low adherence rate (Cameron et al., 2001; Deshmukh, 2013; Pekka Kannus et al., 2000; Van Schoor et al., 2002). These determinants were: poor aesthetic appearance, uncomfortable, skin irritation or abrasion, bowel irritation, swelling of the legs, hip protector experienced as too hot, uncomfortable in bed, necessitating assistance in toileting, too tight, poor fit, extra effort and time required to don and doff, incompatible with incontinence and restrictive. On the other hand, O'Halloran et al. (2007) reported that higher adherence was associated with softer protector pads, lower grip strength, positive perception of appearance and comfort.

Market analysis showed that hip protector manufacturers use cotton or cotton blended with synthetic fibers to provide maximum comfort and absorbency, spandex to make hip protectors stretchy and soft foam in the inner side of protector pads to provide cushioning. Some hip protectors had detachable pads and some of the hip protectors were without crotch especially designed for incontinent people.

Prospective Design Criteria of the Prototype

Based on the information provided above, the following design criteria were established for the prototype. These design criteria are divided into two elements: functional elements and aesthetic elements:

Functional elements.

1. To protect hip area by reducing impact force.

2. To ensure light weight.
3. To ensure maximum range of motion.
4. To ensure easy don and doff.
5. To ensure comfort.
    a. Tactile:
    b. Thermal:
    c. Wickability
    d. Pressure.
6. To be washable.
7. To be suitable for incontinent people.
8. To be adjustable for different sizes.
9. To ensure proper position of hip protector pads.

Aesthetic elements.

1. To be less noticeable.
2. To provide a positive perception about appearance.
3. To reflect unity in design: texture, line and shape.

Goals

Based on the design criteria developed using The FEA Consumer Needs model, the following specific goals were set for this study:

1. To refine and rank the prospective design criteria of the hip protector based on experts' opinion.
2. To design and develop a prototype integrating the prioritized design criteria.
3. To conduct overnight wear tests to determine the extent to which the prototype fulfills users' subjective requirements.

CHAPTER III

METHOD

The purpose of this study was to design and develop a hip protector prototype for elderly women aged 60 years and over. The study was conducted in two stages: development of a prototype and human wear test.

In this chapter, a comprehensive description of the study methodology is provided. This chapter is divided into two sections: prototype development and human wear test. The prototype development section contains a comprehensive description of the design process that was followed to develop the prototype and the human wear test section contains detailed information on sample, population, protocol of the human wear test, data collection and data analysis for this study.

Prototype Development

In the field of apparel design, prototype development is an iterative process where at first requirements are integrated with the design and then effectiveness of the design is evaluated (Watkins, 1995). As long as the requirements are not met to the optimum extent, designers keep modifying their designs. In this study, the prototype development was conducted in four stages:

1. Ranking of design criteria
2. Ideation of design

3. Selection of design
4. Selection of materials

At the very first stage of prototype development, the prospective design criteria, obtained from literature review, market research and preliminary study, were refined. The refined design criteria employed for this study are listed below:

1. Range of motion
2. Don and doff
3. Light weight
4. Washable
5. Tactile comfort
6. Thermal comfort
7. Tightness/Pressure on skin
8. Incontinency
9. Adjustable
10. Pads
11. Wickability
12. Absorbency
13. Appearance retention

Refined design criteria needed to be ranked for subsequent design processes. Ranking helped to realize the order of importance of the design criteria for integration into the prototype to better address elderly people's requirements.

Ranking of Design Criteria

Five experts (two functional apparel designers, one ergonomist, one gerontologist, one apparel designer) and the researcher ranked the refined design criteria using a priority matrix. The priority matrix is widely used in the field of functional apparel to prioritize design aspects.

Function apparel designers focus on users' full range of activities for developing apparels, ergonomists focus on safety and efficiency of designs, gerontologists emphasize on aging process and problems elderly people encounter in their daily life, and apparel designers focus on aesthetic elements of designs within the context of social and cultural needs. Therefore, including these experts' opinions in the design process using the priority matrix helped to address elderly people's needs appropriately. For the priority matrix, all design criteria are compared with each other and then they are ranked based on their relative importance (Watkins, 1995)

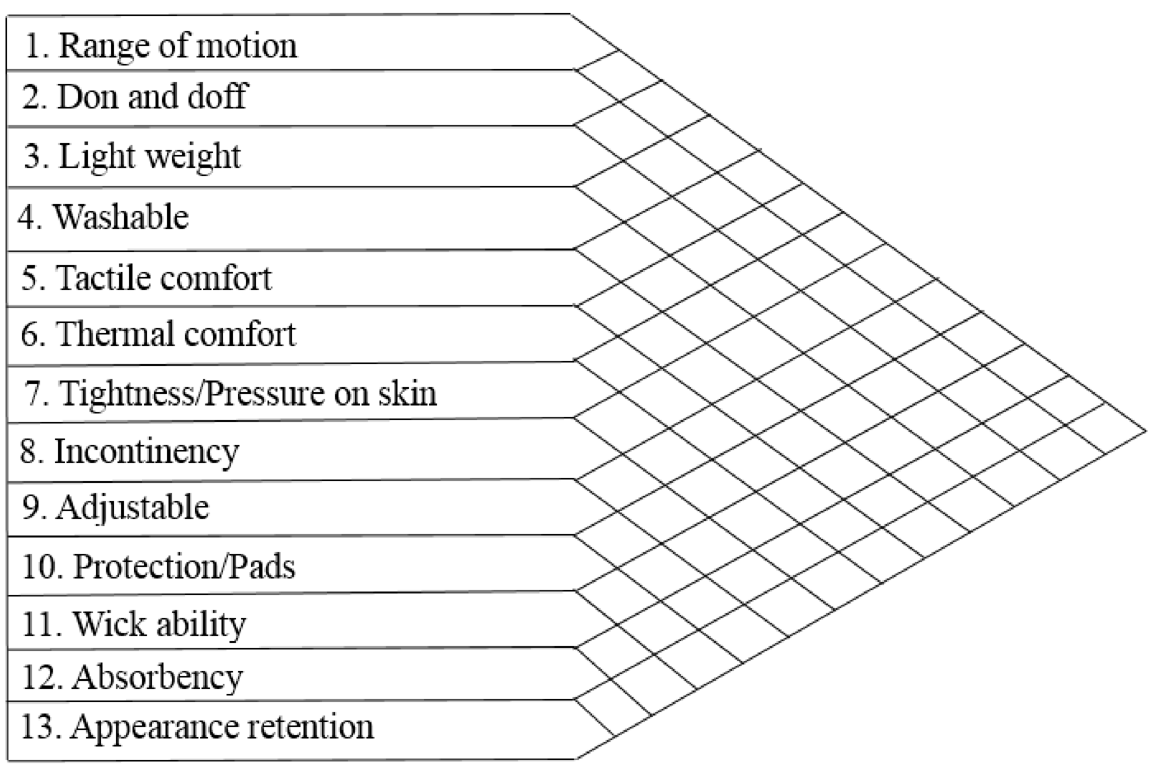

Figure 3.1. Priority matrix

In the above figure, each design criterion was compared. When one design criterion was more important than the other one, it was noted in the respective cell. Such as, for range of motion (1), at first it was compared with don and doff (2). If, according to the evaluator, range of motion (1) was more important than don and doff (2), then s/he would put 1 in the cell next to don and doff (2). Then s/he would compare range of motion (1) with light weight (3). If range of motion (1) was more important, then s/he would put 1 in the right most cell of row 3 in the shaded region. Subsequently, s/he would compare range of motion (1) with each criterion and put the numbers in the corresponding cell diagonally i.e. in the right most cells. Following this procedure, rest of the cells are filled out.

In this study, all six evaluators filled out the priority matrix. Then the number of times each criterion appeared in the priority matrix were accumulated. Criterion with the highest appearance was the most important, with the second highest appearance was the second most important and so forth. Table 3.1 shows the result of priority matrices.

Table 3.1

Result of Priority Matrices

Design criteria	Number of times appeared in the priority matrices
Pads	60
Tightness/Pressure on skin	58
Adjustable	50
Thermal comfort	48
Range of motion	47
Tactile comfort	46
Light weight	33
Wickability	30

Don and doff	29
Incontinency	26
Washable	21
Absorbency	15
Appearance retention	5

According to the priority matrix, integrating pads with the prototype was the most important followed by tightness/pressure on skin. Appearance retention was found out to be the least important criterion. For development of the prototype, efforts were made to address the most important criterion first, then the second most important criterion and so forth. If any design criterion contradicted with another criterion, then whichever had higher importance according to the priority matrix was addressed. For example, fabrics with high wickability usually have low absorbency (Kadolph, 2007). As in this study, wickability was considered more important than absorbency, and wickability and absorbency contradict each other, it was decided to test fabrics for wickability instead of absorbency.

Ideation of Design

Preliminary design ideas, that address the design criteria, were generated. Nonjudgmental and free flow of ideas were considered to create multiple solutions that meet the design criteria. Once ideas were generated, they were scrutinized, and some were modified while some were discarded. After careful consideration, five designs, that meet the design criteria to the maximum extent, were selected (see Figure 3.2).

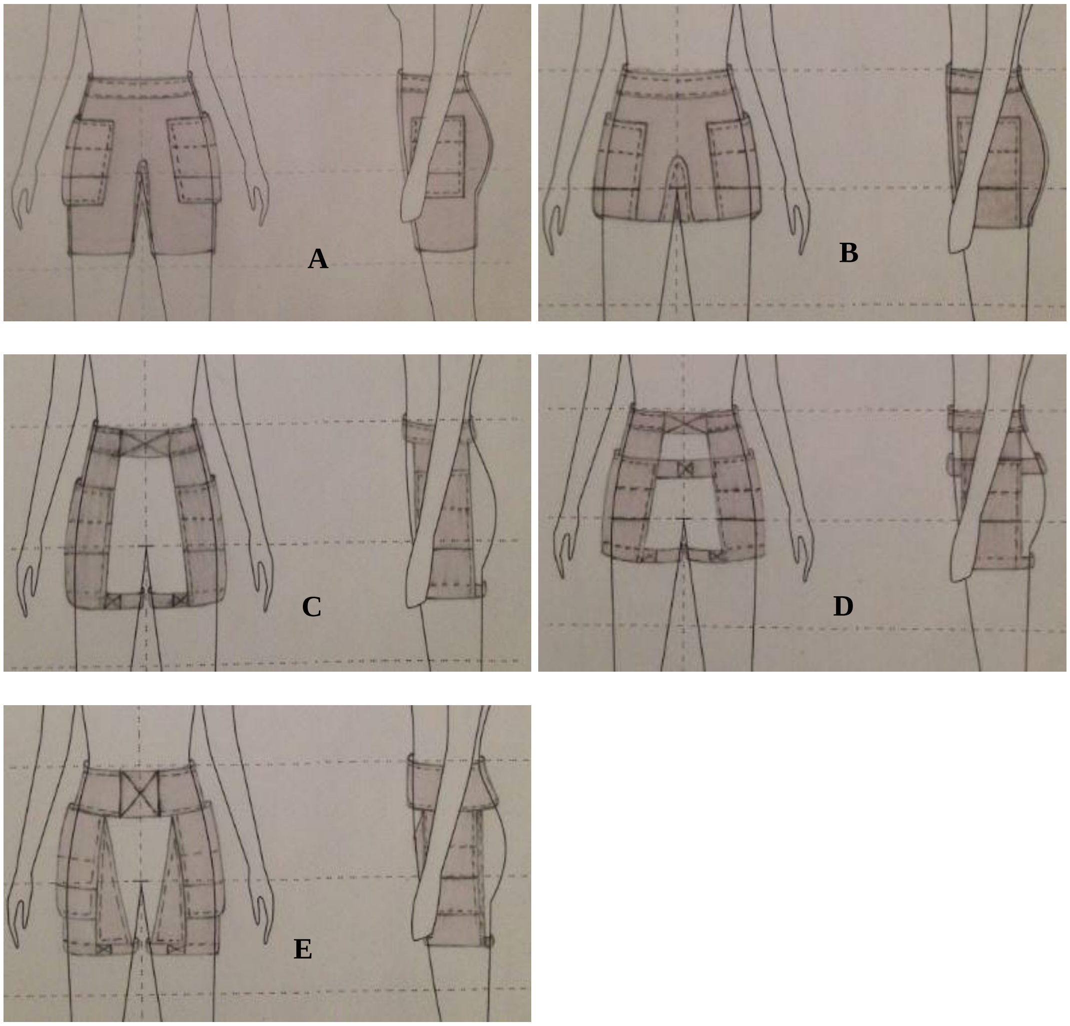

Figure 3.2. Initial five designs. For each design, left is the front view and right is the side view.

Design A and design B are slip-in designs. These two designs are similar to traditional hip protectors. However, they have pockets around crotch to hold absorbent pads. An absorbent pad will absorb urine when people cannot hold urine. People who have weak muscles around their groin tend to have this problem (A. Bishop, personal communication, October 20, 2015). Both designs have pockets on both sides of the hip region to hold hip protector pads. Design B has shorter leg length than design A. However, these two designs are not adjustable at thigh.

The basic structures of the design C, D and E are the same. These three designs are wrap-around design, and have closures at waist and thigh bands. For all three designs, two pieces of fabric are sewn with the waist band and thighs binds. The fabrics cover left and right hip regions, and have pockets sewn into them. These pockets hold the protector pads. For design D, there is a support between the two pockets which runs two-inch below waist line. This support keeps the hip protector pad in place when wearer sits. For design E, there are two triangular pieces of fabric that are sewn with the pocket and thigh bands.

Selection of Design

After selecting five initial designs, the researcher evaluated all the design sketches and selected one design to develop the prototype. Comparison of the five initial designs in terms of the ranked design criteria are provided in the Table 3.2.

Table 3.2

Comparison of Initial Five Designs by the Researcher

Design criteria	Design A	Design B	Design C	Design D	Design E
Pads	√	√	√	√	√
Tightness/Pressure on skin	X	X	√	√	√
Adjustable	X	X	√	√	√
Thermal comfort	5th	4th	1st	2nd	3rd
Tactile comfort	√	√	√	√	√
Light weight	5th	4th	1st	3rd	2nd
Don and doff	3rd	3rd	1st	2nd	1st
Incontinency	√	√	X	X	X

In the Table 3.2, if a design has (√) – the design addresses the design criterion, (X) – the design does not address the design criterion. If the design is ranked such as 1st, 2nd, 3rd etc. then 1st means – best to address the design criterion according to the researcher, 2nd – second best and so forth. If more than one design has the same rank, then they both address the design criterion to the same extent according to the researcher.

During the design stage, all the design criteria of the five designs could not be evaluated. It was assumed that tightness/ pressure on skin and adjustability can be integrated into design C, D and E using hook and loop closures. Lower cover of body ensures higher thermal comfort. Based on this, design C was considered the best design among the five designs in terms of thermal comfort. For easy don and doff, wrap-around design was considered better compared to slip-in design. In addition, design D has an extra closure at the support, so it would take extra time for donning and doffing compared to design C and E.

Based on the comparison table, design C meets the design criteria better than the others. However, upon receiving suggestions from experts, it was realized that, when wearer would sit wearing design C, the pockets that hold the protector pads would move outward as there was no support to keep them in place against thigh. Therefore, researcher decided not to develop design C. Design D has a support to hold the pockets in place, however, the support will dig into flesh between the thigh and the torso when wearer will sit. Finally, it was decided to develop the prototype using design E.

Selection of Materials

Selection of fabric. Fabric selection is a crucial step in the design process. Fabric selection primarily depends on fabrics' compatibility with users' activities and use environment. Fabrics suitable for any specific application may not be suitable for other use conditions. Therefore, the researcher tried to select fabrics that are compatible with elderly people's day-to-day activities and their needs.

All the hip protectors, analyzed during market research, were made of knit fabrics incorporated with spandex. Knit fabric has structural stretchability. Knit fabric incorporated with spandex provides a greater extent of stretch and does not restrict movement. If fabric restricts movement, body metabolism rate increases, eventually leading to higher fatigue and sweating (Watkins, 1995). Therefore, for prototype development, only knit fabrics integrated with spandex was considered to ensure unconstrained range of motion.

Wong and Li (2002) conducted a study with eight sets of tight-fit knit garments where 28 female subjects (age 24.6±5.6) participated a hand evaluation and a wear test. For hand evaluation, subjects rated the fabrics for six sensations: cool, soft, smooth, heavy, prickly and scratchy. For wear test, subjects were asked to run on a treadmill for 20 minutes in a controlled environment (temperature 29^0C±2^0C and relative humidity 85%±3%) and rate each garment at five-minute intervals from time = 0 to time = 20. Subjects rated each of the eight fabrics for nine sensory perceptions: clammy, sticky, breathable, damp, heavy, prickly, scratchy, tight and cool.

The 88% polyester + 12% spandex fabric was rated 1st in both the hand evaluation and the wear test. The 85% nylon + 15% spandex was ranked 2nd in the wear test. In addition, Oğlakcioğlu and Marmarali (2007) showed that regardless of fiber content, because of the structure of single jersey fabric, it had statistically significantly better moisture management properties compared to 1x1 rib and interlock fabrics. The study also revealed that single jersey fabric had lower thermal resistance than that of 1x1 rib and interlock fabric. In this study, thermal comfort was found out to be the fourth most important design criteria. Because fabric of single jersey structure has better thermal conductivity, it was selected for prototype development. Because both nylon and polyester integrated with spandex was selected over cotton in hand evaluation and wear test in previous studies (Wong & Li, 2002), researcher decided to use the following four fabrics for further investigation.

1. Polyester_A – 95% polyester + 5% spandex
2. Polyester_B – 90% polyester + 10% spandex
3. Nylon_A – 95% nylon + 5% spandex
4. Nylon_B – 90% nylon + 10% spandex

Horizontal wicking test. To select the best wicking fabric among the four fabrics, the horizontal wicking test was conducted. As wicking spreads moisture along a wider surface, moisture gets evaporated faster. This helps body to cool down. Furthermore, if fabric does not wick, sweat accumulates at one place and fabric becomes clammy and damp, eventually giving an uncomfortable cold feeling. A Horizontal wicking test was conducted according to AATCC Test Method 198-2011 (American Association of Textile Chemists and Colorists, 2012).

According to the technical manual of the AATCC, the horizontal wicking test can be conducted on both sides of fabrics. It can also be conducted on one side of fabric, however, if it is done on either face or back side of fabrics then it should be done for the same side for all samples to maintain consistency. For this study, the back side of the four fabrics was tested because the back side will be in close contact with skin. To remove the unwanted effect of finishing chemicals on the test result, all four fabrics were laundered according to Standardization of Home Laundry Test Conditions specified in the technical manual of the AATCC.

Laundry procedure. Laundry was conducted in a Maytag top loading washing machine (model number LAT9304AAE). All four fabrics: Polyester A, Polyester B, Nylon A and Nylon B were loaded, washed and dried together. For both washing and drying, the wash cycle – delicate was selected as recommended by the fabric manufacturer. Because no standard detergent is specified in Standardization of Home Laundry Test Conditions for washing, the researcher decided to use Tide HE Ultra Powder Laundry Detergent and Great Value Bleach. After pouring detergent and bleach into the empty washer, it was filled with water. Then the fabrics were loaded and the washer was run with specified parameters (Appendix A).

After washing, fabrics were put in a Maytag front load (model number LDE7304ACE) tumble dryer to dry the fabrics. Fabrics were dried at a maximum exhaust stack temperature of $<62^0$C (144^0F). The cool down time for the dryer was five minutes. Dryer parameters were consistent with the parameters specified in the technical manual of the AATCC. After washing and drying, fabrics were ready for the horizontal wicking test.

Wicking test procedure. The wicking test can be conducted with five cut specimens of 200 x 200 ± 5mm size or without individual cut specimens (AATCC, 2012). In this study, fabrics were not cut into specimens so that they could be reused to make a prototype. According to the technical manual, fabrics need to be conditioned for at least four hours at an atmosphere of 21 ± 1^0C and 65 ± 2% relative humidity (RH). In this study, fabrics were not conditioned prior to the horizontal wicking test as there was no conditioning chamber available in the laboratory. However, fabrics were kept in HSCI 201 overnight under the atmospheric condition of 22 ± 2^0C and 55 ± 5% RH. Both temperature and RH were measured at night and in the following day. For this test, the following apparatus and materials were used: distilled water, a 10 milliliter (mL) pipet with 0.5 mL graduations, a template of 100 mm diameter, a wooden embroidery hoop of 305 mm diameter and a stop watch. The horizontal wicking test procedure is outlined in Appendix B.

Table 3.3 shows experimental data collected during the horizontal wicking test.

Table 3.3

Experimental Data of Horizontal Wicking Test

Fabric	**Sample no**	**d_1 (mm)**	**d_2(mm)**	**t (sec)**	**Wicking rate**
Polyester_A	1	120	130	12.4	988.48
Polyester_A	2	135	148	9.7	1618.41
Polyester_A	3	132	140	10.19	1424.93
Polyester_A	4	132	142	9.7	1518.29
Polyester_A	5	135	148	9.7	1618.41

Polyester_B	6	52	80	148	22.08
Polyester_B	7	63	73	175	20.65
Polyester_B	8	60	83	278	14.07
Polyester_B	9	60	83	213	18.37
Polyester_B	10	58	84	289	13.25
Nylon_A	11	120	140	13	1015.38
Nylon_A	12	120	140	9.5	1389.47
Nylon_A	13	105	130	14.9	719.80
Nylon_A	14	115	138	12.7	981.83
Nylon_A	15	100	132	12.5	829.71
Nylon_B	16	51	43	300	5.74
Nylon_B	17	66	45	300	7.78
Nylon_B	18	64	40	300	6.71
Nylon_B	19	79	51	300	10.55
Nylon_B	20	70	53	300	9.72

Collected data were analyzed using SAS® version 9.4 statistical software to determine which fabric had the highest horizontal wicking rate.

Nonparametric ANOVA. To compare sample means of two or more than two groups, one-way analysis of variance (ANOVA) is used. Parametric ANOVA assumes that (i) observations are independent, (ii) residuals are normally distributed and (iii) all groups have equal variance (Freund & Wilson, 2003). However, in this study, the horizontal wicking rate did not comply with the assumptions of parametric ANOVA. Hence, nonparametric Kruskal-Wallis ANOVA was applied to the data. Nonparametric tests do not assume that samples are drawn from a Gaussian distribution. In addition, nonparametric analysis depends on ranks of data rather than values, and it is suitable for small sample size (Freund & Wilson, 2003). The Kruskal-Wallis test was conducted assuming the following null hypothesis

H: The wicking rates were from identical populations i.e. there was no significant difference between the medians of wicking rate of all four fabrics.

Results of the Kruskal-Wallis test for the wicking rate is summarized in Table 3.4. The analysis was conducted at a 5% level of significance.

Table 3.4

Wilcoxon Scores (Rank Sums) for Wicking Rate Classified by Fabric

Fabric	N	Sum of scores	Expected under H_0	Standard deviation under H_0	Mean score
Nylon_A	5	67.0	52.50	11.45	13.40
Nylon_B	5	15.0	52.50	11.45	3.00
Polyester_A	5	88.0	52.50	11.45	17.60
Polyester_B	5	40.0	52.50	11.45	8.00

Kruskal-Wallis Test	
Chi-Square	17.3445
DF	3
Pr > Chi-Square	0.0006*

Note. * indicates significant at $p \leq 0.05$ level.

The p-value is 0.0006 which is less than the specified level of significance. Therefore, there was sufficient evidence to reject the claim that medians of horizontal wicking rate of the four fabrics were equal. At least one of the horizontal wicking rate medians appeared to be different from the others. To determine which fabric had the highest wicking rate, the Dwass, Steel, Critchlow-Flinger (DSCF) multiple comparison analysis was conducted (Douglas & Michael, 1991). This multiple comparison is based on pairwise two-sample Wilcoxon comparisons. Table 3.5 displays the outcome of the pairwise multiple comparison.

Table 3.5

DSCF Pairwise Two-Sided Multiple Comparison Analysis to Determine Highest Wicking Rate

Fabric	Wilcoxon Z	DSCF value	Pr > DSCF
Nylon_A vs Nylon_B	2.6112	3.6927	0.0447
Nylon_A vs Polyester_A	-2.2001	3.1113	0.1232*
Nylon_A vs Polyester_B	2.6112	3.6927	0.0447
Nylon_B vs Polyester_A	-2.6191	3.7040	0.0437
Nylon_B vs Polyester_B	-2.6112	3.6927	0.0447
Polyester_A vs Polyester_B	2.6191	3.7040	0.0437

Note. *indicates significant at $p \leq 0.05$ level

The result shows that there is no significant difference between the horizontal wicking rates of Nylon_B and Polyester_B. In contrast, Nylon_A and Polyester_A both have significantly higher horizontal wicking rates than that of Nylon_B and Polyester_B. However, the horizontal wicking rate of Nylon_A and Polyester_A are not significantly different from each other. Hence, it can be concluded that, among the four fabrics tested, either Nylon_A or Polyester_A should be used to develop the hip protector prototype. Next, the researcher evaluated hand of both Nylon_A and Polyester_A in terms of weight of the fabric, fabric surface smoothness and fabric surface softness. The researcher decided to used Polyester_A because of its better hand. The researcher's decision is also in congruent with a previous study where polyester was rated better than nylon for its hand (Wong & Li, 2002).

Selection of notions. Garment notions were chosen in such a way that they complemented the garment design in both aesthetically and functionally. For the selected design of the hip protector prototype, the waist band, thigh bands and fastening system needed to be selected.

By an extensive online market research, the researcher found that there were five types of elastic bands widely used in garments manufacturing: braided elastic, knit elastic, cord elastic, buttonhole elastic and drawstring elastic. For lingerie and swimwear, knit elastics are primarily used because of their smooth surface and durable stretchability. Therefore, the researcher decided to use knit elastic for both waist and thigh bands because they would be in close contact with bare skin. Width of the bands were determined by observing athletic wear. In addition, the waist band and thigh bands should be wide and sturdy enough to hold the protector pads firmly against the hip region. A two-inch wide waist band and one-inch wide thigh bands were chosen to fulfill the requirements.

Primary functions of the fastening systems include, but not limited to, providing shape and form to a garment, easy and quick don and doff, adjustment and fitting. (Watkins, 1995). A wide array of fastening systems: hook and loop tape, hooks and eyes, snaps, buttons, magnet etc. were evaluated in terms of users' needs and limitations. The hook and loop tape was selected after careful consideration of elder women's dexterity. In addition, hook and loop tape is easy to secure and detach, which will help the wearers to don and doff the hip protector. For determining the position of the fastening systems, researcher considered the need for easy accessibility. For this reason, the hook and loop closures for thigh bands were placed at the middle of the frontal thigh of both the right and left leg.

Prototype

The prototype was developed using Polyester A, a two-inch wide waist band, two one-inch wide thigh bands and hook and loop closure. The prototype was developed based on the measurements of a fit model – a Caucasian female over 60 years of age. Using a fit model provided the opportunity to check fit, drape, visual appearance and functionality of the hip protector prototype. Body measurements that were used to develop the hip protector prototype are listed in the Table 3.6.

Table 3.6

Measurements for the Fit Model

Position	Measurement (in inch)
Waist (at belly button)	34 ¾
Hip (7inch below waist)	38
Crotch level (front to back)	26 ¾
Upper thigh (2 ½ below hip line)	21 ¼
Mid-thigh (6 ½ below hip line)	19 ½
Crotch depth	10
Waist to greater trochanter	5 ½
Hip to greater trochanter	1 ½

After developing the initial prototype using deign E, it was realized that the support held the pockets in place but when the wearer would sit, the support would pull the pockets towards front. In addition, it is to be noted that for standing to sitting, the diagonal distance between A to B (shown in Figure 3.3) reduces by one and a half inch and the distance between C to D increases by half an inch. To accommodate the extension and contraction of distances, elastic bands were sewn in to a casing between A and B, and C and D. Although, the diagonal distance between A and B reduces by one and a half inch, when the prototype was developed and tested, it was found that one and a half inch shorter elastic could not hold the hip protector pad in place i.e. the protector pad would move outward. To address this, the elastic band was made two and a half inches shorter than the actual distance between A and B. Similarly, it was found that to keep the protector pad in place, the elastic band between C and D needed to be one inch shorter than the actual distance.

The prototyping process also included evaluation of the elastic. At first, half an inch wide elastic tape was sewn in between A and B, and C and D. However, the half an inch wide elastic tape did not provide the needed extension and contraction. Thus the half an inch elastic tapes were replaced with one-inch wide knit elastic. The knit elastic was the same type of elastic that was used for the thigh band.

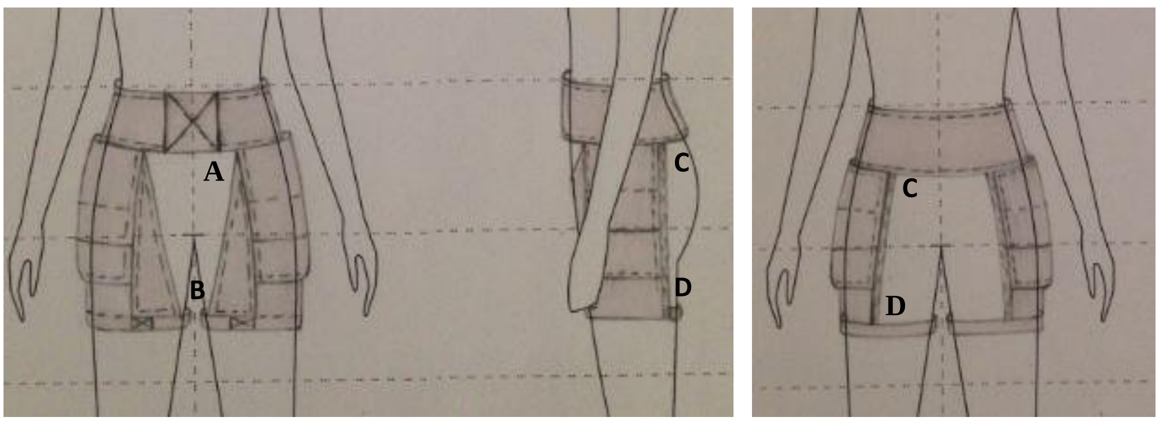

Figure 3.3. Front and side view (left) and back view (right) of design E.

The hip protector prototype has one pocket on each side of the hip region to hold the protector pads. The protector pads were made detachable so that users could take them out and wash the hip protector prototype. The pockets which hold the protector pads have two flaps: the top flap and bottom flap. The flaps were designed in such a way that they overlap each other by one and half inch. The shape of the flap patterns was engineered to an oval shape to accommodate the thickness of the pads and to lay them flat. To remove or place the protector pads in the pocket, the overlapped flaps are pulled out and the protector pads are slipped in. The polyester-spandex blend of the chosen fabric enabled the opening to stretch for insertion, yet hold the protector pads firmly in position.

Protector pad. In this study, FallGard Hip Protector Pads, US Patent 5636377 are used (Figure 3.4). The dimensions of the protector pads are: length – 6 ½ inch, width – 4 ½ inch and height – ½ inch. The same hip protector pads were used for all five human wear tests to control the effect of hip protector pads. A prior empirical study showed that combined pad hip protector pads provided more protection against impact energy than hard pad and soft pad (Kannus et al., 1999), hence, a combined pad hip protector was selected for this study.

Figure 3.4. The protector pads used in the study

The final prototype was analyzed to determine whether it fulfilled the design criteria to the fullest extent. Table 3.7 summarizes the design criteria that were integrated into the hip protector prototype.

Table 3.7

Summary of the Design Criteria and How They Were Integrated in the Final Prototype

Design criteria	Methods of incorporation
Pads	Design has pockets on both sides around hip region to hold protector pads.

Tightness/Pressure on skin	Stretchable fabric, elastic waist and thigh band provides elasticity. Hook and loop closures at waist and thigh band provide the option to adjust pressure on skin.
Adjustable	Addressed by incorporating hook and loop closures at waist and thigh bands. There is also a detachable three inch waist band extension.
Thermal comfort	Relatively small body coverage ensures higher heat loss by convection. Single jersey fabric is used. Because of its structure, single jersey fabric has lower thermal insulation property than double jersey fabric.
Range of motion	Design does not hinder natural range of motion. In addition, fabric with spandex stretches during movement.
Tactile comfort	Knit elastic band with smooth surface, and soft and smooth surfaced single jersey fabric were used.
Light weight	Fabric of lower unit weight was selected. Light weight waist and thigh bands were used.
Wickability	Fabric with the highest wickability was used.
Don and doff	Hook and loop closure ensured easy donning and doffing. The design is not a slip-in, it is detachable at waist. Hence easy to put on and take off.
Incontinency	Does not address this problem. However, people who need to use restrooms more frequently, they can complete their necessity without taking the hip protector off.
Washable	Hip protector is machine washable. Pads are detachable, so they can be taken off before laundry.

The developed prototype (Figure 3.5) addressed 11 out of 13 design criteria (Table 3.9). Absorbency was not addressed because absorbency contradicts with wickability. Generally, fabrics with high wickability have low absorbency (Kadolph, 2007). Wickability was considered more important according to the six raters of this study, hence, in the context of this study, it was reasonable to address wickability. In addition, appearance retention found out be the least important design criterion, therefore, it was not addressed in this study.

Figure 3.5 Final prototype (left to right – front, side and back view)

Human Wear Test

Research Design

An experimental research method was employed to collect responses from subjects. Subjects were recruited from Stillwater, Oklahoma. Subjects were approached using the purposive sampling method. For the scope of this study, the purposive sampling method is appropriate as it focuses on collecting data from subjects who have particular characteristics that are of interest (Patten & Bruce, 2010).

Population

The population of the study consisted of ambulant elderly women aged 60 years and over who live in Stillwater, Oklahoma. Although osteoporosis, a disease of progressive bone weakness and fragility that is primarily responsible for increased risk of fractures, starts developing in both men and women as early as 50 years of age (AAOS, 2016), hip fracture incidences are more prevalent among the population age 60 years and over (CDC, 2015). Therefore, the age group of 60 years and over was the ideal age group for this study.

Sample

Five women over 60 years of age were recruited from Oklahoma State University of Stillwater, Oklahoma for the human wear test. In the field of functional apparel design, evaluation of prototypes using sample size as small as five is not unusual (Pandolf, 1995; Peksoz, 2005). Subjects needed to meet the following inclusion criteria: a) waist between 33 and 40 inch, b) age 60 years and over, c) ambulant with or without assisted devices – subjects can walk, move, change clothing and use restrooms without human assistance, c) do not have cognitive disorders, and d) are not under prescribed psychotropic and sedative medications.

Variables of Interest

The primary variable of interest of the human wear test was to determine the participants' subjective perception of the developed prototype. To determine wearers' perceptions of the hip protector prototype, perception of mobility, perception of fit, perception of comfort, perception of tactile characteristics and ease of don and doff were investigated. Subjects' perception of overall design was also investigated.

Questionnaires

The FEA Consumer Needs Model was combined with the design criteria and the specific design components of the prototype to develop open-ended and closed-ended questions. A scale was adopted from the Comfort Affective Labeled Magnitude (CALM) scale which was developed to measure handle and comfort of military clothing fabrics (Cardello, Winterhalter, & Schutz, 2003). The scale used in this study is an 11-point ordinal scale, ranging from '-100' to '+100' with an interval of 20, where '-100' means 'greatest imaginable discomfort' and '+100' means 'greatest imaginable comfort' with '0' as 'neither comfortable nor uncomfortable'.

Data Collection

Prior to the beginning of subject recruitment for the human wear test, the researcher applied for approval from the Institution Review Board (IRB) of Oklahoma State University to conduct an experiment involving human subjects. Upon receiving approval, the recruitment email was sent to all staff of two colleges at Oklahoma State University. When interested subjects reported, they were scheduled to meet at the place of their convenience. In the meeting, at first, researcher ensured that subjects met the inclusion criteria. If subjects met the inclusion criteria, the scope of the study, protocols, potential benefits, risk of participation and measures taken to protect subjects' confidentiality were explained. The researcher also showed them the hip protector prototype and the proper way of wearing it. After being adequately briefed about the study, if subjects agreed to volunteer for the study, they were asked to come to our lab wearing a pair of pants at a time of their convenience.

Protocol. The human wear tests were conducted in three phases: phase-01: lab test, phase-02: overnight wear test and phase-03: interview.

***Phase-01: lab test*.** Subjects came to the lab. First, subjects were asked to provide their written consent for participation. Then researcher showed them the proper way of wearing the hip protector prototype and explained the activities. The researcher provided a chair and a bed. The subjects wore the hip protector prototype on top of their pants and performed the following activities once at their normal pace in front of the researcher in the lab.

I. Standing to sitting
II. Sitting to standing
III. Sitting to lying
IV. Lying to sitting
V. Walking 10 meters.

The same chair and bed were used for all five subjects. To ensure all subjects walked the same distance, two marks were drawn on the floor. Subjects walked from the first mark on one side of the room to the second mark. After reaching the second mark, subjects turned around and walked back to the starting position. Then subjects were asked to take the hip protector off and fill out the phase-01 questionnaire (Appendix C). The researcher helped the subjects if they found any of the questions difficult to understand. During the phase-01 test, the ambient temperature was 22 ± 2^0C. However, because the lab was not equipped to regulate relative humidity, relative humidity ranged from 45% to 65%. After completing the phase-01 questionnaire, subjects took the hip protector prototype to their place of residence to perform the overnight wear test. Subjects were provided with written instructions about how to wear the hip protector prototype, the phase-02 questionnaire, the protocol of the study and a phone number to contact the researcher if they had any questions.

Phase-02: overnight wear test. Subjects wore the hip protector prototype overnight at their place of residence. They were given the choice to wear the hip protector prototype underneath their night gown, with or without undergarment, over their undergarment, over their pajamas or however they wanted to wear it. Subjects were asked to wear the hip protector prototype with their regular sleeping clothes because wearing different clothing for a specific night might have affected their regular sleeping habit and confound their perception of comfort of the hip protector prototype. Subjects were given the following instructions for the overnight wear test:

- To complete their before-sleep necessary activities before they wore the hip protector prototype.
- To wear the hip protector as demonstrated by the researcher. If subjects found it difficult to don the hip protector prototype, they were asked to refer to the 'instructions for wearing the hip protector prototype'.
- To ensure proper placement of the waist band, thigh band and protector pads as demonstrated by the researcher.
- To ensure that the waist band and thigh band were not too snug to prevent them from becoming uncomfortable over time.
- To sleep in their regular sleeping position.
- To avoid taking the hip protector prototype off if they woke up in the middle of the night to perform any necessary activities. If they had to take the hip protector prototype off, they were asked to take it off right before the necessity and put it back on as soon as the

necessity was over. Subjects could get up from bed as many times as they wanted or needed.

- To do everything normally as they would do in a typical night.

Subjects were asked to fill out the phase-02 questionnaire (Appendix D) as soon as they woke up in the following day.

Phase-03 Interview. Subjects met the researcher at the place of their convenience to conduct the post wear test interview (Appendix E). The researcher noted their responses and retrieved the hip protector prototype. After each human wear test, the pads were removed and the hip protector prototype was laundered and disinfected according to the laundry procedure (Appendix A).

Data Analysis

Two types of data were collected during this experimental study: quantitative data and qualitative data. Quantitative data were collected during phase 01 and phase 02 using two separate questionnaires and qualitative data were collected during post wear test interviews. Although phase 01 and phase 02 questionnaire had open ended questions, none of the subjects responded to them. Hence, phase 01 and phase 02 questionnaires were analyzed using statistical methods, and interviews were analyzed to identify themes and determine the essence of textual data.

Quantitative data were analyzed using SAS® 9.4 statistical software and Microsoft Excel 2016, and qualitative data were analyzed using NVivo 11. Quantitative data analysis included descriptive statistics, Wilcoxon signed rank test for one sample, Wilcoxon signed rank text for paired sample and Kruskal-Wallis test with appropriate post hoc tests. For all statistical analyses, a significant level of 0.05 was used unless otherwise specified. As there were only five subjects in this study, only nonparametric statistical methods were considered. Prior to data analysis, researcher examined responses to identify missing values. Because there were no missing values in the dataset, missing value imputation was not conducted in this study. For qualitative data analysis, the framework approach was applied (Smith & Firth, 2011).

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CHAPTER IV

FINDINGS

This chapter describes the findings of the study. It is divided into two sections: quantitative findings and qualitative findings. The quantitative section starts with information about descriptive statistics about the subjects. Later, in this section, results of the Wilcoxon signed rank test for one sample, Wilcoxon signed rank test for paired sample and Kruskal-Wallis test are provided. The qualitative section provides the framework approach to the findings of the interview data.

Quantitative Findings

The study was conducted in three phases: phase 01, phase 02: overnight wear test and 03: post wear test interview. Quantitative data was collected after phase 01 and phase 02 through two separate questionnaires. Both questionnaires were self-administered, however, the researcher interpreted questions if any of the subjects found them hard to understand.

Subject Descriptive

An email invitation to participate in the study was sent to all staff of College of Human Sciences and College of Agricultural Sciences and Natural Resources. Four subjects were recruited from the aforementioned two colleges and one subject was recruited by networking through professors. All the subjects reported that they never used hip protector before. One of the subjects experienced two falls in her home while doing household chores. Except for her, none of the subjects had ever experienced fall. One of the subjects reported that she always sleeps wearing an undergarment underneath a nightgown and rest of the subjects reported to sleep in wearing either loose fitting pants or nightgowns without any undergarment underneath. All subjects stated that they always cover their body with a thin comforter and a sheet during night time. Descriptive statistics of the subjects are provided in the Table 4.1. The table shows that the mean age of subjects was 62 years (SD = 1.73). Subjects had the mean height of 65 inch (SD = 2.24) and mean waist circumference of 35.1 inch (SD = 2.75).

Table 4.1

Descriptive Statistics of the Subjects

Variable	Minimum	Maximum	Mean	SD
Age	61	65	62	1.73
Height (in inch)	62	68	65	2.24
Waist circumference (in inch)	33.5	40	35.1	2.75

Perception of Comfort

The one sample t-test determines whether the mean of a sample is equal to a specified value. The Wilcoxon signed rank test is the substitute for a one sample t-test for nonparametric analysis and it determines whether the median of a sample is equal to a specified value (Freund & Wilson, 2003).

In this study, subjects provided their perceptions of comfort about the hip protector prototype for both phase 01 and phase 02 using the same 11-point scale which ranged from '-100' to '+100' with an interval of 20, where '-100' means 'greatest imaginable discomfort' and '+100' means 'greatest imaginable comfort' with '0' as 'neither comfortable nor uncomfortable'. Phase

01 questionnaire (Appendix C) included 14 items: 'perception of feeling at the – waist, thigh, inner thigh while moving legs, on both hips around the pad, waist band being adjustable, thigh band being adjustable, position of hook and loop closures on thigh bands, body temperature, overall weight, putting on, taking off, while standing, while sitting and while lying, and phase 02 questionnaire (Appendix D) included 13 items: 'perception of feeling – putting on, look, movements while lying on a bed, sleeping position, fabric against skin, falling asleep, body temperature, overall weight, design, waist band being adjustable, thigh band being adjustable, taking off and overall design'. For the Wilcoxon signed rank test, '+80' (extremely comfortable) of the scale was specified as the base value to test whether subjects' perception varied from '+80' for any of the above mentioned items both in phase 01 or phase 02. For the one sample t-test analysis, '+80' was selected as the base value because the researcher assumed that the subjects would have very high positive perceptions. Results are given in the Table 4.2 and Table 4.3.

Table 4.2

Results of One-Sample Wilcoxon Signed Rank Test for Perception of Comfort for Phase 01

Perceived comfort	Mean	Median	SD	Interquartile range	Signed rank	P-value
Waist	72	80	22.80	20	-1.5	0.75
Thigh	56	80	53.66	80	-2	0.625
Inner thigh while moving legs	56	80	43.36	60	-2	0.50
Both hips around pad	80	80	20.00	40	0	1.00
Waist band – adjustable	84	80	16.73	20	1	1.00
Thigh band – adjustable	76	80	26.07	40	-1	1.00
Position of closure on thigh band	80	80	24.50	20	0	1.00

Body temperature	84	80	16.73	20	1	1.00
Overall weight	88	80	10.95	20	1.5	0.50
Putting on	80	80	0	0	-	-
Taking off	84	80	8.94	0	0.5	1.00
Standing	88	80	10.95	20	1.5	0.50
Sitting	88	80	10.95	20	1.5	0.50
Lying	88	80	10.95	20	1.5	0.50

Note.'100' – greatest imaginable comfort, '80' – extremely comfortable, '60' – very comfortable, '40' – moderately comfortable, '20' – slightly comfortable, '0' – neither comfortable nor uncomfortable, '- 20' – slightly uncomfortable, '- 40' – moderately uncomfortable, '- 60' – very uncomfortable, '- 80' – extremely uncomfortable, '- 100' – greatest imaginable discomfort.

Table 4.3

Results of One-Sample Wilcoxon Signed Rank Test for Perception of Comfort for Phase 2

Perceived comfort	Mean	Median	SD	Interquartile range	Signed rank	P-value
Putting on	84	80	8.94	0	0.5	1.00
Look	60	60	42.43	60	-3.5	0.50
Movements while lying	80	80	0	0	-	-
Sleeping position	80	80	0	0	-	-
Fabric against skin	84	80	8.94	0	0.5	1.00
Falling asleep	84	80	8.94	0	0.5	1.00
Body temperature	84	80	8.94	0	0.5	1.00
Overall weight	80	80	14.14	0	0	1.00
Design	80	80	14.14	0	0	1.00
Waist band – adjustable	84	80	8.94	0	0.5	1.00
Thigh band – adjustable	80	80	14.14	0	0	1.00

Taking off	84	80	8.94	0	0.5	1.00
Overall feeling	84	80	8.94	0	0.5	1.00

Note.'100' – greatest imaginable comfort, '80' – extremely comfortable, '60' – very comfortable, '40' – moderately comfortable, '20' – slightly comfortable, '0' – neither comfortable nor uncomfortable, '- 20' – slightly uncomfortable, '- 40' – moderately uncomfortable, '- 60' – very uncomfortable, '- 80' – extremely uncomfortable, '- 100' – greatest imaginable discomfort.

Result shows that none of items of phase 01 and phase 02 is significantly different from '+80' – extremely comfortable. In other words, all the subjects considered the hip protector prototype to be extremely comfortable for all the 14 items of phase 01 and 13 items of phase 02.

Perception of mobility. In this study, subjects provided their perceptions of mobility about the hip protector prototype after phase 01 (Appendix C). Then they provided their perceptions on a five-point scale with '1' representing 'hip protector has not restricted my mobility at all', '2' – slightly restricted my mobility, '3' – moderately restricted my mobility, '4' – extremely restricted my mobility and '5' – so confining that I could not move. For the Wilcoxon signed rank test, '1' of the scale was specified as the base value to test whether subjects' perception varied from '1' for any of the activities they performed. Results are given in the Table 4.4.

Table 4.4

Results of One-Sample Wilcoxon Signed Rank Test for Perception of Mobility

Item	Mean	Median	SD	Interquartile range	Signed rank	P-value
Stand-to-sit	1	1	0	0	-	-
Sit-to-stand	1	1	0	0	-	-
Sit-to-lie	1	1	0	0	-	-
Lie-to-sit	1	1	0	0	-	-

Walk 10 meters	1.2	1	0.45	0	0.5	1.00

Note. '1' – hip protector has not restricted my mobility at all, '2' – slightly restricted my mobility, '3' – moderately restricted my mobility, '4' – extremely restricted my mobility and '5' – so confining that I could not move'.

Results show that for four activities: stand to sit, sit to stand, sit to lie and lie to sit signed rank could not be calculated as all subjects selected 1 – hip protector has not restricted my mobility at all. In addition, for walking 10 meters, subjects' responses did not change significantly from 1.

Influence of Extended Wear and Sleep

The paired t-test compares mean values of matched pairs i.e. means of pre and post experiment data are compared for the same criteria. In this study, nonparametric paired t-test – the Wilcoxon signed rank test was conducted. Instead of comparing means, the Wilcoxon signed rank test for paired sample compares medians of paired samples. For Wilcoxon signed rank test, pre-experiment values are deducted from post-experiment values for the respective criteria and it is tested whether the difference is statistically significant (Freund & Wilson, 2003).

In this study, subjects were asked to provide their perceptions about the hip protector prototype on the 11-point scale. Subjects provided their responses for the same seven items for both phase 01 and phase 02 (Appendix C and D). Perceptions were measured for the following seven items: 'putting on, taking off, waist band being adjustable, thigh band being adjustable, body temperature, overall weight and overall feeling'. Responses were compared using Wilcoxon signed rank test to determine whether there were any changes in perceptions for short-time and long-time wear tests. In this study, perceptions after short-time is defined as subjects' perceptions after phase 01 and perceptions after long-time is defined as subjects' perceptions after phase 02. Univariate analysis of perceptions of short-time and long-time wear test, and results of the Wilcoxon signed rank test are given in the Table 4.5 and Table 4.6.

Table 4.5

Univariate Analysis of Perceptions of Short-time and Long-Time Wear Test

Condition (Independent factors)	Wearing – short time			Wearing – Long time		
Dependent variables	Mean	Median	SD	Mean	Median	SD
Body temperature	84	80	16.73	84	80	8.94
Overall feeling	88	80	10.95	84	80	8.94
Overall weight	88	80	10.95	80	80	14.14
Putting on	80	80	0	84	80	8.94
Taking off	84	80	8.94	84	80	8.94
Thigh band being adjustable	76	80	26.07	80	80	14.14
Waist band being adjustable	84	80	16.79	84	80	8.94

Note.'100' – greatest imaginable comfort, '80' – extremely comfortable, '60' – very comfortable, '40' – moderately comfortable, '20' – slightly comfortable, '0' – neither comfortable nor uncomfortable, '- 20' – slightly uncomfortable, '- 40' – moderately uncomfortable, '- 60' – very uncomfortable, '- 80' – extremely uncomfortable, '- 100' – greatest imaginable discomfort.

Table 4.6

Results of Wilcoxon Signed Rank Test for Short-time and Long-time Wear Test

Dependent variables	Mean difference	Median difference	SD	Interquartile range	Signed rank S	P - value
Body temperature	0	0	20	40	0	1.00
Overall feeling	-4	-20	16.73	20	-1	1.00
Overall weight	-8	-20	15.12	20	-2.5	0.625
Putting on	4	0	8.94	0	0.5	1.00

Taking off	0	0	14.14	0	0	1.00
Thigh band being adjustable	4	20	21.91	40	1.5	1.00
Waist band being adjustable	0	0	20	40	0	1.00

Note. * indicates significant at $p \leq 0.05$ level.

Results show that perception about the hip protector prototype did not change significantly for any of the seven items. Subjects perceptions on the seven items for short-time wear test were ‘extremely comfortable’ and they did not change after the overnight wear test.

Variations among Test Subjects

Among 5 subjects, one subject (subject 03) experienced falls before and the rest of the subjects never experienced falls before. Study showed that people who experienced falls were more positive towards using hip protectors (Hubacher, 2001) Therefore, it was decided to determine the differences in perceptions among the five subjects. To determine whether subjects had different perceptions about the hip protector prototype, Kruskal-Wallis test with appropriate post hoc test was employed to test for location. As subjects provided their responses for phase 01 and phase 02 using two separate questionnaires, the Kruskal-Wallis test was performed separately for both phase 01 and phase 02 responses. The Kruskal-Wallis tests were performed assuming the following null hypotheses for both phase 01 and phase 02

H_{pre}: The perceptions in phase 01 were from identical population i.e. there was no difference between the medians of perceptions of all five subjects in phase 01.

H_{post}: The perceptions in phase 02 were from identical population i.e. there was no difference between the medians of perceptions of all five subjects in phase 02.

Variations among test subjects in phase 01. In phase 01, subjects’ perceptions about the hip protector prototype were measured on 14 items (mentioned in one-sample t-test section) using the 11-point scale (Appendix C). Initially, there were 15 items. The item – "how the fabric of the hip protector prototype felt against skin" was discarded from phase 01 questionnaire because all the subjects wore the hip protector prototype on top of their pants for phase 01 and they could not provide their responses for this item. The rest of the 14 items were analyzed. Results of the analysis are provided in the Table 4.7 and Table 4.8.

Table 4.7

Analysis of Variance of Responses for Phase 01

Subject number	N	Mean	SD
Subject 1	14	94.29	9.3761
Subject 2	14	80.00	0.00
Subject 3	14	58.57	22.8227
Subject 4	14	62.86	32.2081
Subject 5	14	98.57	5.3452

Source	Degrees of freedom	Sum of squares	Mean square	F – value	Pr > F
Among	4	18137.143	4534.286	13.54	<0.0001
Within	64	21771.429	334.945		

Table 4.8

Wilcoxon Scores (Rank Sums) for Responses for Five Subjects

Subject number	N	Sum of scores	Expected under H_0	SD under H_0	Mean score
Subject 1	14	712.00	497.00	62.7691	50.86

Subject 2	14	427.00	497.00	62.7691	30.50
Subject 3	14	239.50	497.00	62.7691	17.11
Subject 4	14	309.00	497.00	62.7691	22.07
Subject 5	14	797.50	497.00	62.7691	56.96

Kruskal-Wallis Test	
Chi-Square	49.3559
DF	4
Pr > Chi-Square	0.0001*

Note. * indicates significant at $p \leq 0.05$ level.

The p-value is 0.0001 which is less than the specified level of significance. Therefore, there was sufficient evidence to reject the claim that medians of perceptions of five subjects for phase 01 were equal. At least one of the subject's perceptions appeared to be different than the others'. To determine which subject's perceptions were significantly different than the others', the DSCF multiple comparison analysis was conducted. Table 4.9 displays the results of multiple comparison conducted based on pairwise two-sample Wilcoxon comparisons.

Table 4.9

DSCF Pairwise Two-Sided Multiple Comparison Analysis for Phase 01

Subject number	Wilcoxon Z	DSCF value	Pr > DSCF
Subject 1 vs subject 2	3.8730	5.4772	0.0010*
Subject 1 vs subject 3	4.1486	5.8670	0.0003*
Subject 1 vs subject 4	3.9773	5.6248	0.0007*
Subject 1 vs subject 5	-1.4536	2.0557	0.5928
Subject 2 vs subject 3	3.2327	4.5717	0.0108*

Subject 2 vs subject 4	2.4108	3.4093	0.1124
Subject 2 vs subject 5	-4.8374	6.8411	<0.0001*
Subject 3 vs subject 4	-1.0303	1.4571	0.8414
Subject 3 vs subject 5	-4.6463	6.5709	<0.0001*
Subject 4 vs subject 5	-4.6485	6.5740	<0.0001*

Results show that perceptions of subject 1 and subject 5 are not significantly different from each other. However, their perceptions are significantly higher than perceptions of subject 2, 3 and 4. On the other hand, subjects 2, 3 and 4 do not have significantly different perceptions about the hip protector prototype.

Variations among test subjects in phase 02. In phase 02, subjects' perceptions about the hip protector prototype were measured on 13 items using the 11-point scale (Appendix D). Results of the analysis are provided in the Table 4.10 and Table 4.11.

Table 4.10

Analysis of Variance of Responses for Phase 02

Subject number	N	Mean	SD
Subject 1	13	83.08	7.5107
Subject 2	13	95.38	8.7706
Subject 3	13	73.85	9.6077
Subject 4	13	76.92	11.094
Subject 5	13	73.85	22.188

Source	Degrees of freedom	Sum of squares	Mean square	F – value	Pr > F

Among	4	4283.08	1070.77	6.37	0.0002
Within	60	10092.31	168.21		

Table 4.11

Wilcoxon Scores (Rank Sums) for Responses for Five Subjects

Subject number	N	Sum of scores	Expected under H_0	SD under H_0	Mean score
Subject 1	13	449.00	497.00	47.8398	34.54
Subject 2	13	685.00	497.00	47.8398	52.69
Subject 3	13	288.00	497.00	47.8398	22.15
Subject 4	13	362.00	497.00	47.8398	27.85
Subject 5	13	361.00	497.00	47.8398	27.77

Kruskal-Wallis Test	
Chi-Square	33.1829
DF	4
Pr > Chi-Square	<0.0001*

Note. * indicates significant at $p \leq 0.05$ level.

The p-value is 0.0001 which is less than the specified level of significance. Therefore, there was sufficient evidence to reject the claim that medians of perceptions of five subjects for phase 02 were equal. At least one of the subject's perceptions appeared to be different than the others'. To determine which subject's perceptions were significantly different than the others', the DSCF multiple comparison analysis was conducted. Table 4.12 displays the results of multiple comparison conducted based on pairwise two-sample Wilcoxon comparisons.

Table 4.12

DSCF Pairwise Two-Sided Multiple Comparison Analysis for Phase 02

Subject number	Wilcoxon Z	DSCF value	Pr > DSCF
Subject 1 vs subject 2	-3.0861	4.3644	0.0173*
Subject 1 vs subject 3	2.4390	3.4493	0.1051
Subject 1 vs subject 4	1.7103	2.4188	0.4275
Subject 1 vs subject 5	1.7103	2.4188	0.4275
Subject 2 vs subject 3	3.9670	5.6102	0.0007*
Subject 2 vs subject 4	3.9322	5.5610	0.0008*
Subject 2 vs subject 5	3.9322	5.5610	0.0008*
Subject 3 vs subject 4	-1.3089	1.8511	0.6857
Subject 3 vs subject 5	-1.3089	1.8511	0.6857
Subject 4 vs subject 5	0.0555	0.0784	1.00

Results show that perceptions of subject 1 and subject 2 are not significantly different from each other. Perceptions of subject 2 are significantly higher than that of all other subjects. Whereas, perceptions of subject 1 are not significantly different than perceptions of subject 3, 4 and 5. Hence, it can be concluded that perceptions of subject 1 are higher than that of all other subjects.

Qualitative Findings

After the overnight wear test, each subject was interviewed individually using an open ended questionnaire (Appendix E) at the place of her convenience. Subjects were asked questions related to their perceptions of comfort, functionality etc. of the hip protector. Their responses were noted for further analysis.

To analyze qualitative data, the framework approach was applied. The framework approach is widely used when aims and objectives of the research is highly focused, unlike other inductive approaches such as grounded theory where research is an iterative process to explore underlying patterns (Smith, 2011). However, in the framework approach, at first, textual data is organized through the process of summarization and then significant themes are identified for further analysis.

In this study, subjects were asked questions related to different aspects of the developed prototype. They were asked to provide responses related to their perceptions of mobility, comfort, donning and doffing, effectiveness of the design to perform activities during overnight wear test, and different aspects and fabric of the hip protector prototype. As the primary purpose of the interview was to explore wearers' perception, at first, the researcher categorized responses in two types: negative perceptions and positive perceptions. Then, these two categories were further explored and the following subcategories were created to analyze wearers' perceptions specific to the subcategories: design, functionality, closure, fabric, pads, and thigh and waist band. As subjects were asked specifically about the aforementioned six subcategories, coding textual data for these subcategories appropriately addressed the purpose of this study.

NVivo 11 was used to perform a word frequency query. A word frequency query identifies words that are most frequently mentioned by subjects. It also incorporates weighted percentage, which explains importance of any specific word relative to all words that are coded. Figure 4.1 shows word frequency of the interview data.

Figure 4.1. Most frequently occurring words in post-overnight wear test interview.

Auxiliary verbs, prepositions and articles were excluded from the word frequency query. In addition, stemmed words, which means different forms of a verb such as talk, talks, talking, talked etc. were coded together, and synonyms were also considered for the analysis. The result showed that position, protector, thigh, hip, good, band, affect, pads etc. were some of the words that were repeatedly mentioned in the interview.

A matrix coding query analysis was conducted for both positive perceptions and negative perceptions to explore the relationship between subcategories and the number of sentences coded, and how they were related to positive and negative perceptions. Positive and negative perceptions were identified depending on the descriptive nature of the comments. Table 4.13 and Table 4.14 shows results of matrix coding query for positive and negative perceptions respectively in relation to design and functionality.

Table 4.13

Matrix Coding Query for Positive Perceptions

	Closure	Fabric	Pads	Thigh and waist band
Design	18	18	15	18
Functionality	42	43	39	42

Table 4.14

Matrix Coding Query for Negative Perceptions

	Closure	Fabric	Pads	Thigh and waist band
Design	2	3	6	7
Functionality	2	3	6	7

The matrix coding query results showed that all subcategories, the number of sentences that belonged to positive perceptions were 3 to 21 times higher than the number of sentences that belonged to negative perceptions, reflecting a higher degree of acceptance of the hip protector prototype among all the subjects.

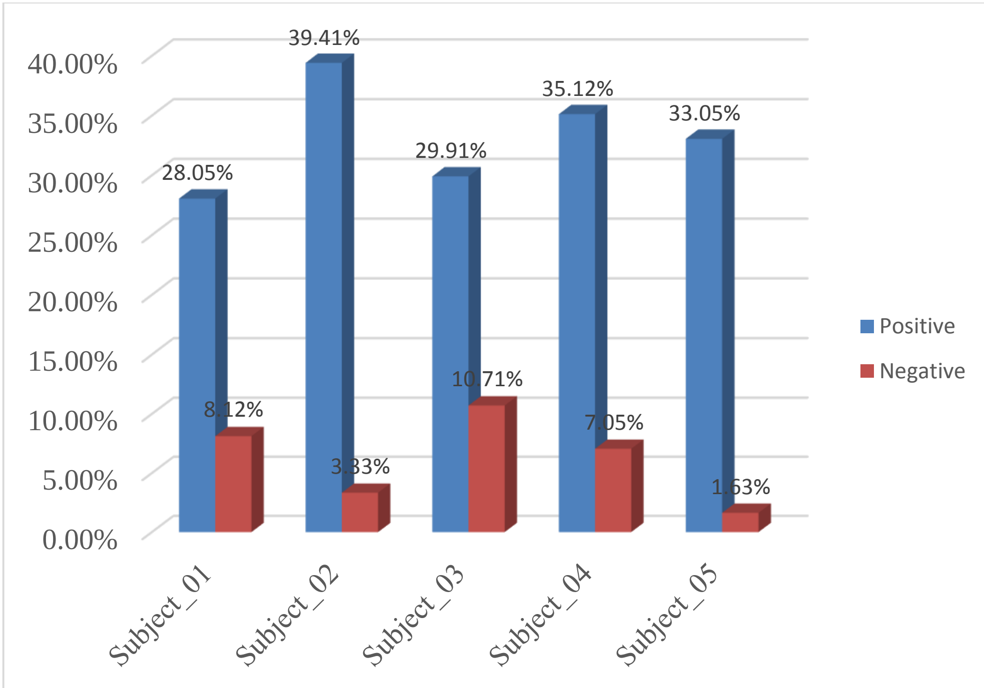

Figure 4.2. Comparison of positive and negative perceptions of five subjects.

Figure 4.2 shows comparison of positive perceptions and negative perceptions about the hip protector prototype among the five subjects. Negative perceptions were substantially lower than positive perceptions for all the five subjects. Such as, for subject five, 33.05% of total interview data belonged to positive perception, whereas, only 1.63% of total data were considered to be negative perception

In this study, a hip protector prototype was developed by integrating design criteria which were prioritized by five experts. Subjects evaluated the developed prototype in three phases and provided their perceptions. Then subjects' perceptions were analyzed to explore acceptability of different design aspects of the hip protector prototype among the subjects.

CHAPTER V

DISCUSSION

An interpretive discussion of the study findings is outlined in this section. The primary purpose of this study was to develop a hip protector prototype based on users' requirements and subsequently evaluate the prototype to determine the extent to which the hip protector prototype fulfilled those specified requirements.

A review of literature, an analysis of focus group interviews and findings from market research helped to determine users' requirements. The FEA Consumer Needs Model was utilized as a framework to develop design criteria to address users' requirements. The design criteria were rated by experts and then a hip protector prototype was developed integrating those design criteria. During the evaluation stage, wearers wore the hip protector prototype and performed certain activities that simulate basic movement and range of motion. Wearers also wore the hip protector prototype overnight. Afterward, wearers provided their perceptions about the hip protector prototype. Wearers' perceptual data were analyzed to determine acceptability of the hip protector prototype among the subjects.

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In published studies, subjects repeatedly mentioned about two of the problems as barriers to hip protector adoptions which were the hip protectors being too tight and movement restrictive. In addition, subjects also reported that the leg hem of hip protectors dug into their flesh when they wore hip protectors for more than a couple of hours, especially when someone had thick thighs (Peter D. O'Halloran et al., 2007). To address this problem, the hip protector prototype was developed integrating knit elastic as the waist band and thigh bands. In addition, hook and loop closures were used at waist and thigh band which provided adjustability up to two and half inches. Adjustability provided wearers the freedom to control pressure around their thigh and hip regions. The integration of knit elastic as waist and thigh bands was highly acceptable among subjects of this study, and evaluated as extremely comfortable among the subjects of this study. To make the hip protector less restrictive, a polyester-spandex blend fabric was used. The findings of the perceptual data related to mobility revealed that the hip protector provided a full range of motion which was obtained through stretch and elasticity of the polyester-spandex blend fabric coupled with elastic waist and thigh bands. Analyzing of perceptual data related to mobility also showed that the subjects considered the hip protector prototype to be completely nonrestrictive, ascertaining that subjects did not have to work against the hip protector while they performed the activities.

One of the problems, associated with existing hip protectors reported in the previous studies, was the heavy weight of the device (Deshmukh, 2013). The weight of the hip protector is primarily depended on the weight of the protector pads. Commercially available hip protector pads were used in this study so it was not possible to change the weight of the pads, nevertheless, low gram per unit weight of fabric was selected to reduce overall weight of the hip protector prototype. Furthermore, light weight knit elastic bands selected as the waist and thigh bands also helped to ensure low overall weight of the hip protector prototype. In addition, the pockets which hold the hip protector pads were designed in a way that no closure was required at the pockets, lessening the overall weight of the developed prototype. Analysis of data revealed that the subjects did not consider the hip protector prototype to be heavy, and they perceived it to be 'extremely comfortable' in terms of overall weight.

During initial selection of fabric, smoothness of fabric surface was considered. Because hip protectors were worn in close contact with the skin, a rough fabric surface resulted in skin irritation and abrasion when wearers wore them for prolonged period, leading to a low acceptability rate among wearers (Peter D O'Halloran et al., 2007). To ensure that wearers could wear the hip protector prototype for long period, smooth surfaced polyester knit fabric was selected. The waist and thigh bands also had smooth surfaces. Smoothness of fabric, waist and thigh bands helped subjects wear the hip protector prototype overnight without feeling any discomfort or skin irritation as reflected by the subjects' high positive perceptions about the hip protector prototype against their skin.

It was also reported that wearers stopped wearing hip protectors because hip protectors made them feel hot, and low thermal comfort was reported as one of the major reasons for low adherence rate among wearers (Butler, Coggan, & Norton, 1998; Van Schoor, Devillé, Bouter, Lips, & Lips, 2002). To provide maximum thermal comfort to wearers, in this study the hip protector was designed to provide a low cover on the body as lower cover ensures higher evaporation of heat. In addition, single jersey knit structure was selected because research showed that this fabrication provides low thermal insulation (Oğlakcioğlu & Marmarali, 2007). Body dissipates a significant amount of heat through evaporation (Fan & Hunter, 2009). Wickability of fabric aids in evaporation by spreading moisture along the fabric surface. Hence, a polyester spandex blend fabric with a high wickability rate was selected for the prototype development. Being made of a polyester single jersey knit fabric and having a low-cover design ensured high thermal comfort to wearers which was revealed by the analysis of subjects' perceptual data related to thermal comfort.

Investigation of low adherence rate of hip protectors among wearers living in nursing homes revealed that wearers primary concern was about the design of hip protectors for being incompatible with their need to use restrooms frequently. They also expressed their concern about the extra effort needed to don and doff a slip-in design (Hubacher & Wettstein, 2001). With age, people tend to lose their ability to maintain balance (El Haber, Erbas, Hill, & Wark, 2008). Therefore, a slip-in design, where one must raise one leg for donning and doffing, makes elderly people more fall prone. Considering elderly people's needs related to donning and doffing, this study's hip prototype was developed using a wrap-around design. In addition, the hip protector prototype was made crotchless to accommodate elderly people's need of frequent restroom use. Findings of the study showed that subjects highly appreciated the purposeful design of the prototype that accommodated these factors. Interestingly, some of the subjects even envisioned some problems that they might had encountered if the prototype design was a slip-in.

In summary, according to FEA Consumer Needs Model, product development requires identification of users' requirements. Users' requirements are usually use-situation specific, so solutions are generated considering the use-situation. Successful implementation of solutions leads to higher acceptability of a product (Lamb & Kallal, 1992). In this study, in order to increase the adherence rate of hip protectors, at first, users' requirements related to hip protectors were identified and solutions were generated to address the requirements. Those solutions were then integrated into the newly designed prototype. Overall, successful identification of design criteria and effective integration of those design criteria into the prototype led to higher acceptability of the developed prototype among the subjects.

CHAPTER VI

CONCLUSION

The purpose of this study was twofold: first, to develop a hip protector prototype integrating the design criteria that were obtained through review of literature, intensive market research and analysis of focus group interviews, and second, to evaluate the developed prototype in terms of user acceptance of the integrated design criteria. The evaluation was conducted in three phases where wearers provided their perceptions about different aspects of the hip protector prototype. Subsequently the perceptual data were analyzed to assess the acceptability of the hip protector prototype among the wearers.

Findings indicate that subjects' perceptions about different aspects of the hip protector prototype were highly positive for all three phases. Wearers reported that the hip protector prototype did not restrict their mobility at all for any of the activities: standing to sitting, sitting to standing, sitting to lying, lying to sitting and walking for 10 meters, which they performed in the laboratory of the College of Human Sciences.

Wilcoxon signed rank test analysis of perceptual data showed that wearers perceptions did not differ significantly from 'extremely comfortable' for both phase 01 and phase 02. In other words, wearers considered the hip protector prototype to be extremely comfortable for both phase 01 and phase 02.

In addition, Wilcoxon signed rank test for paired sample was conducted to determine whether wearers' initial perceptions, which ranged between 'very comfortable' and 'extremely comfortable', changed after overnight wear test. Findings of the paired test showed that overnight wear test did not affect wearers' initial perceptions about the hip protector prototype significantly i.e. after overnight wear test, subjects considered the hip protector prototype to be between 'very comfortable' and 'extremely comfortable'.

Kruskal-Wallis analysis findings revealed that although overall perceptions of some of the subjects were significantly different from that of others, none of the subjects' overall perceptions were below the 'very comfortable' level. Findings also revealed that overall perceptions of the hip protector were as high as 'greatest imaginable comfort' for one subject. In addition, one subject who experienced falls before did not have significantly different perceptions about different aspects of the hip protector prototype.

Qualitative data analysis also showed high acceptability of the hip protector prototype among all five subjects. Subjects repeatedly appreciated the design of the hip protector prototype for being crotchless which made it compatible with wearers' need of frequent restroom use during nighttime. Subjects also liked the position of the closures at the thigh bands for being easily accessible Except for one subject for whom the thigh band did not fit properly, the rest of the subjects liked the width and thickness of the thigh bands. All subjects liked the fabric and the waist band. Except for one subject who recommended to make the prototype more feminine, all subjects liked the design for keeping the protector pads in place when they rolled over during sleeping. Overall, all subjects had a very high positive perception about the hip protector prototype.

Limitations

There were several limitations associated with this study that the researcher could not control. First, the horizontal wicking test was conducted according to the AATCC Test Method

198-2011 but prior to the test, samples needed to be conditioned at 21 ± 1^0C and 65 ± 2% RH for four hours. Because there was no conditioning chamber in the laboratory, samples were not conditioned. However, samples were kept in the laboratory at 22 ± 2^0C and 55 ± 5% RH overnight. Therefore, it was assumed that the effect of RH on the horizontal wicking test was minimal. Second, the study was conducted with five subjects aged 60 years and over who were recruited from Stillwater, Oklahoma. Therefore, findings cannot be generalized to the entire 60 years and over population of Oklahoma. Third, thigh circumference was not a subject selection criterion. Therefore, the thigh band did not fit one subject properly as she had thinner thighs. Because of this, she had slightly negative perceptions about the thigh band. However, making the Hook and loop closure three-inches long can address the problem as it will give three additional inches to adjust for different thigh widths. Fourth, subjects wore the hip protector prototype overnight underneath or over their regular sleeping wear and the ambient temperature at the subjects' residence was not controlled. Therefore, subjects' perceptions might have been influenced either because of their night wear or the temperature at their place of residence. However, the researcher did not want to make any change in subjects' regular sleep environment or sleep wear because it was assumed that changing sleep environment or sleep wear would confound subjects' perceptions. Last, subjects provided their perceptions after performing certain activities at the laboratory and after overnight wear test. Their perceptions do not necessarily reflect their perceptions if they were asked to wear the hip protector prototype during regular daytime activities. Therefore, subjects' perceptions about the hip protector prototype are specific to the activities they performed and the overnight wear test.

Future Research

Considering the limitations of the study mentioned in the previous section, certain future researches are recommended. The evaluation phases of the developed prototype included certain activities performed in the laboratory and an overnight wear test. Asking subjects to wear the hip protector prototype during day time while doing day-to-day activities will provide deeper insight into subjects' perceptions about the hip protector prototype. In this study, there was only one subject who experienced falls before. Comparing perceptions of fallers and non-fallers with a higher number of subjects in each group will help designers to understand whether special attention needs to paid to design hip protectors for fallers. In this study, participants provided their subjective perceptions of mobility. Inclusion of objective measurement of mobility using 3D motion capture will enable researchers to determine the extent of mobility restriction by the hip protector prototype.

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APPENDICES

Appendix A

Washing Parameters

Category	Parameters
Tide powder detergent	3/8 of a cup (85 grams)
Liquid bleach	½ cup (118 milliliter)
Wash temperature	27^0C ± 3^0C (80^0F ± 5^0F)
Rinse temperature	< 29^0C (<85^0F)
Water level	19 ± 1 gallon
Agitation speed	27 ± 2 strokes per minute
Washing time	8.5 minute
Spin speed	500 ± 15 revolutions per minute
Final spin time	3 minute

Appendix B

Laundry procedure

The laundry procedure:

1. Using the template, five 100 mm diameter circles were drawn and centers were marked with a permanent marker on the back side (test side) of each of the four fabrics. Each circle was drawn 500 mm apart from each other. Each circle was assigned a sample number starting from one.
2. The test fabric was inserted into the embroidery hoop in such a way that one drawn circle (sample 1) was in the middle of the embroidery hoop.
3. A pipet was filled with 10 mL distilled water and was held at the center of the circle. The tip of the pipet was 10 mm above the surface of the fabric.
4. Distilled water was dispensed at the center of the circle in 10 ± 2 seconds.
5. The timer was started as soon as distilled water started to dispense.
6. The timer was stopped immediately after distilled water reached the perimeter of the circle. Elapsed time was noted.
7. If distilled water reached the perimeter before 10 mL was dispensed, the timer was stopped as soon as distilled water reached the perimeter and the elapsed time was noted.
8. The test was terminated if water did not reach the perimeter in 5 minutes. In this case, elapsed time was 5 minutes or 300 seconds.
9. Wicking distances were measured lengthwise and widthwise at the highest spreads.
10. The horizontal wicking rate was calculate using the following formula

    $W = \pi * (1/4) * d_1 * d_2 / t$

    Where, W = Wicking rate

    d_1 = Wicking distance in length direction in mm

    d_2 = Wicking distance in width direction in mm

t = Wicking time in second

11. Above mentioned steps were repeated for rest of the four drawn circles.

12. Wicking rates were calculated for all four fabrics according to formula in step 10.

Appendix C

Phase 01 Questionnaire

<u>Subject number:</u>

<u>Phase -01 after initial wear-test (1st Questionnaire)</u>

Participant number:

1. Age: ………………...
2. Height: ………………...
3. Waist circumference: ………………...
4. I usually sleep
    a. Alone
    b. Holding a pillow/body pillow
    c. With my partner/husband
    d. With my pet(s)
    e. With my kid(s)/grandkid(s)
    f. Other (please specify) ………………...
5. I usually wear ………………... to sleep in
    a. Long tight fitting pants
    b. Long loose fitting pantNight gown with undergarment underneath
    c. Night gown without undergarment underneath
    d. Multiple layers, for example tights underneath pajama pants.
    e. Nothing
    f. Other (please specify) ………………...
6. I cover my body with ………………... while I sleep (select as many as apply)
    a. Thick Comforter
    b. Thin comforter/Blanket
    c. Quilt

d. A sheet

e. Nothing – I do not cover myself

f. Other (please specify) ………………...

7. Have you ever used a hip protector before?

a. Yes

b. No

8. Have you experienced a fall before? (If your answer is No, please skip to the next section)

a. Yes

b. No

9. How would you describe your fall? If you experienced multiple falls, please select 'Other' and describe each of them using choices a, b and c. For example: if you experienced 2 falls – first one on your side and second one on your back then write: Other, first – a, second – b

a. On my side

b. On my back

c. On my front

d. Other ………………...………………...………………...

10. How would you describe the situation of your fall?

a. In the home

i. Taking the stairs

ii. Walking to the restroom

iii. In the restroom

iv. Doing household chores

v. Outside of your house except public spaces

vi. Getting up from bed during the night time

vii. Other (please specify) ………………...

b. In public spaces

i. Taking the stairs
ii. Walking to the restroom
iii. In the restroom
iv. Getting in and out of the car
v. Inside of a store, church or other public space etc.
vi. Other (please specify) ………………...

Following the scale below, please circle the appropriate number that best reflects your opinion

1 – Hip protector has not restricted my mobility at all

2 – Hip protector slightly restricted my mobility

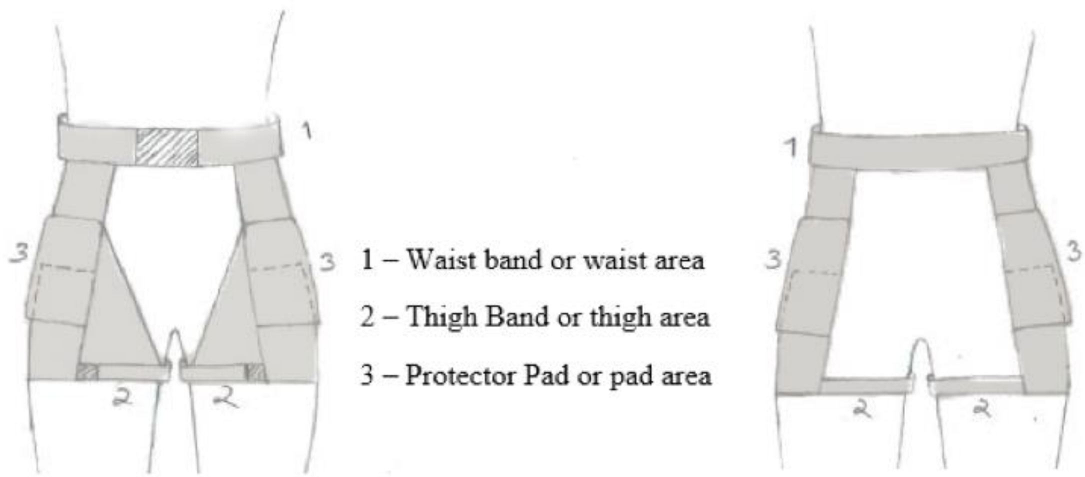
3 – Hip protector moderately restricted my mobility

4 – Hip protector extremely restricted my mobility

5 – Hip protector is so confining that I could not move

1. Standing to sitting	1	2	3	4	5

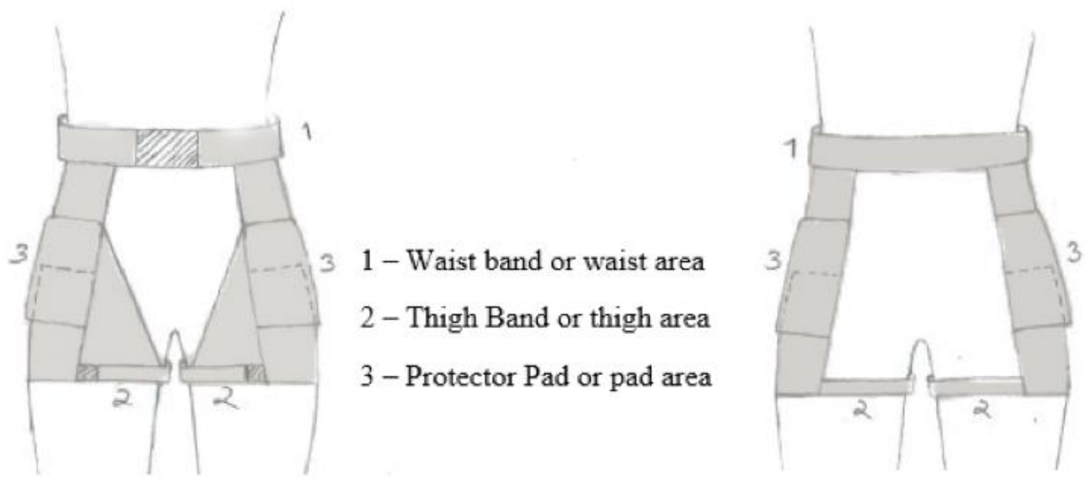
If any particular area restricted your '**Standing to sitting**' activity, please indicate the spot by marking (x) anywhere on the below sketch.



Front View Back View

2. Sitting to standing 1 2 3 4 5

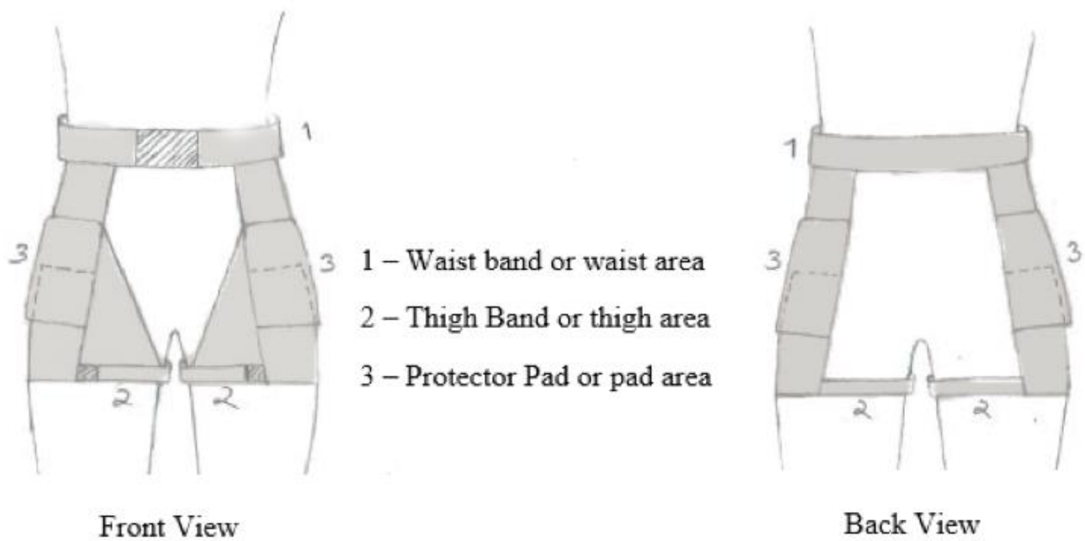
If any particular area restricted your '**Sitting to standing**' activity, please indicate the spot by marking (x) anywhere on the below sketch.



Front View Back View

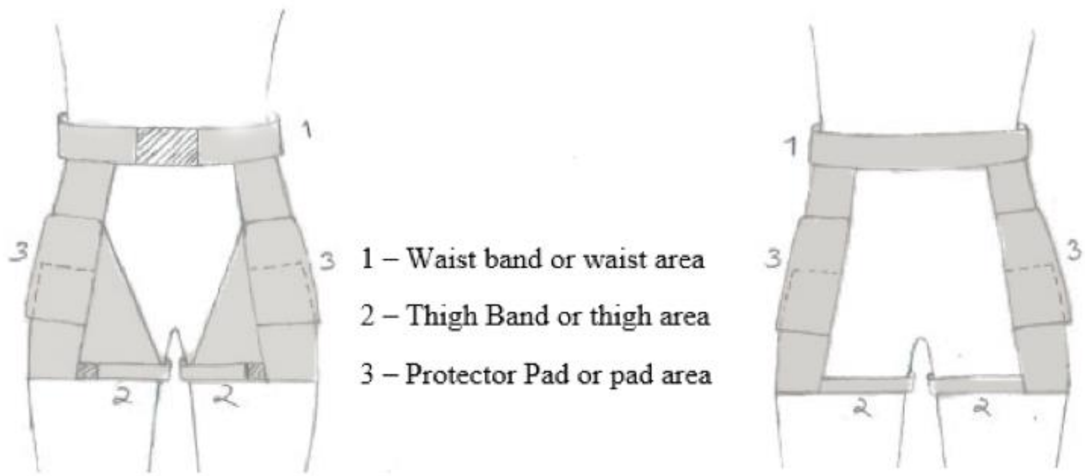
3. Sitting to lying 1 2 3 4 5

If any particular area restricted your ‘**Sitting to lying**’ activity, please indicate the spot by marking (x) anywhere on the below sketch.



4. Lying to sitting 1 2 3 4 5

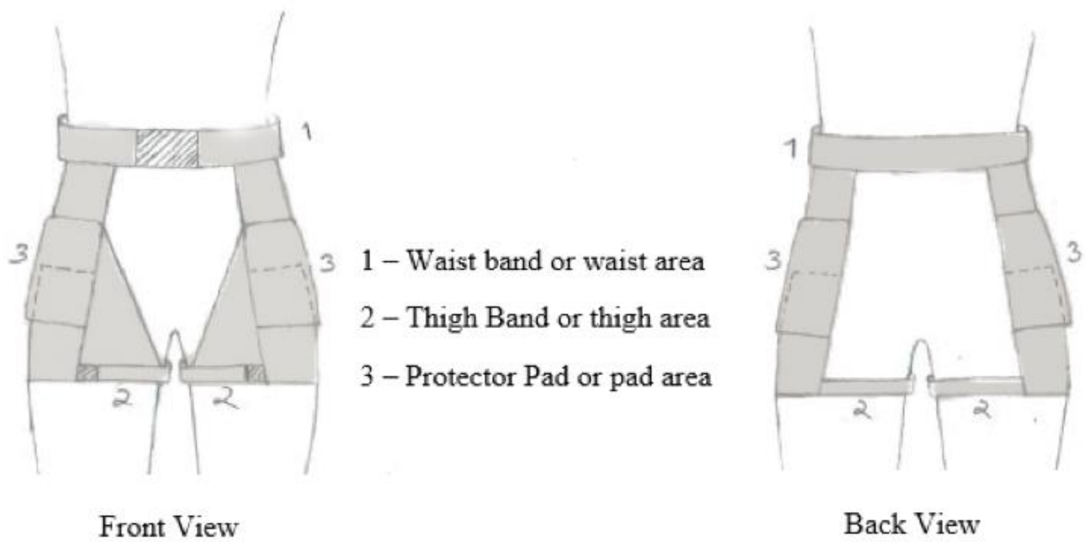
If any particular area restricted your '**Lying to sitting**' activity, please indicate the spot by marking (x) anywhere on the below sketch.



Front View Back View

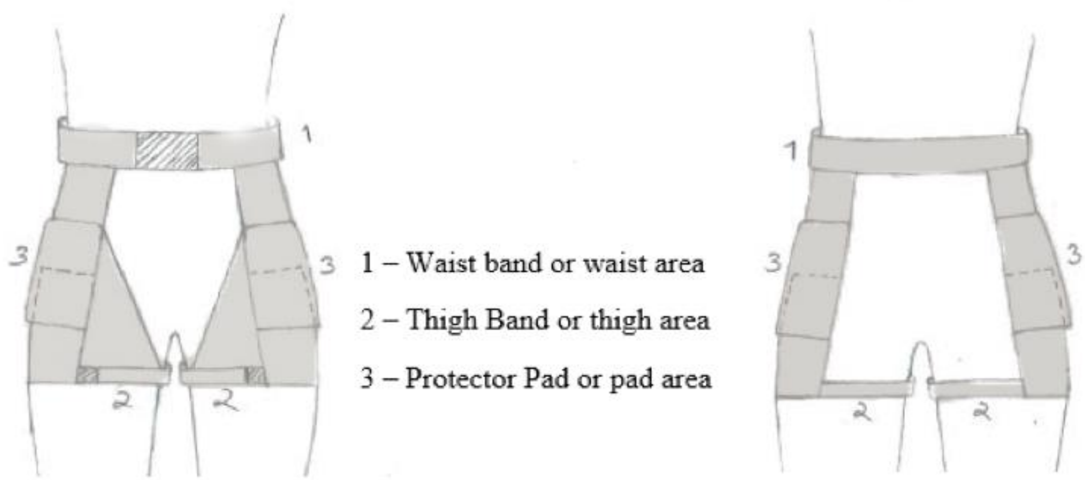
5.	Walking 10 meter	1	2	3	4	5

If any particular area restricted your '**Walking 10-meter**' activity, please indicate the spot by marking (x) anywhere on the below sketch.



Following the scale below, please indicate your level of comfort by circling the appropriate number after the question. Please refer to the sketch if you need clarification about the area mentioned in any question.

100 ------------	Greatest Imaginable Comfort
80 ------------	Extremely Comfortable
60 ------------	Very Comfortable
40 ------------	Moderately Comfortable
20 ------------	Slightly Comfortable
0 ------------	Neither Comfortable nor Uncomfortable
-20 ------------	Slightly Uncomfortable
-40 ------------	Moderately Uncomfortable
-60 ------------	Very Uncomfortable
-80 ------------	Extremely Uncomfortable
-100------------	Greatest Imaginable Discomfort



Front View

Back View

1. Feeling at waist area	100	80	60	40	20	0	-20	-40	-60	-80	-100
2. Feeling at thigh area	100	80	60	40	20	0	-20	-40	-60	-80	-100
3. Feeling at inner thigh area when you moved your legs	100	80	60	40	20	0	-20	-40	-60	-80	-100
4. Feeling on both hips around the pad area	100	80	60	40	20	0	-20	-40	-60	-80	-100
5. Feeling about the waist band of the hip protector being adjustable	100	80	60	40	20	0	-20	-40	-60	-80	-100
6. Feeling about the thigh band of the hip protector being adjustable	100	80	60	40	20	0	-20	-40	-60	-80	-100
7. Feeling about the **position** of the Velcro (Hook and loop) adjustment on the thigh band	100	80	60	40	20	0	-20	-40	-60	-80	-100
8. Feeling about the material/fabric of the hip protector against your skin	100	80	60	40	20	0	-20	-40	-60	-80	-100
9. Feeling in terms of body temperature after wearing the hip protector	100	80	60	40	20	0	-20	-40	-60	-80	-100
10. Feeling about overall weight of the hip protector	100	80	60	40	20	0	-20	-40	-60	-80	-100
11. Felling about putting on the hip protector	100	80	60	40	20	0	-20	-40	-60	-80	-100

12. Feeling about taking off the hip protector	100	80	60	40	20	0	-20	-40	-60	-80	-100
13. Overall feeling about the hip protector while you are **standing**	100	80	60	40	20	0	-20	-40	-60	-80	-100
14. Overall feeling about the hip protector while you are **sitting**	100	80	60	40	20	0	-20	-40	-60	-80	-100
15. Overall feeling about the hip protector while you are **lying**	100	80	60	40	20	0	-20	-40	-60	-80	-100

Appendix B

Phase 02 Questionnaire

<u>Subject number:</u>

<u>Phase – 02 after overnight wear-test (2nd Questionnaire)</u>

1. Last night I slept
    a. Alone
    b. Holding a pillow/body pillow
    c. With my partner/husband
    d. With my pet(s)
    e. With my kid(s)/grandkid(s)
    f. Other (please specify) ………………...
2. I wore the hip protector
    a. Over my undergarment
    b. Without any undergarment
    c. Other (please specify) …………….
3. Last night I wore ……………. Over the hip protector
    a. Long tight fitting pants
    b. Long loose fitting pants
    c. Night gown with undergarment underneath
    d. Night gown without undergarment underneath
    e. Multiple layers, for example tights underneath pajama pants.
    f. Nothing
    g. Other (please specify) ………………...
4. Last night I covered myself with ………………... (select as many as apply)
    a. Thick Comforter

b. Thin comforter/Blanket

c. Quilt

d. A sheet

e. Nothing – I did not cover myself

f. Other (please specify) ………………...

5. How was your last night's sleep compared to your typical night sleep?

a. I slept like I usually do

b. I woke up 1 to 2 times more than usual

c. I woke up 3 or more times more than usual

d. I had more difficulty falling asleep, but after I started sleeping I slept like usual

e. I slept poorly

f. I could not sleep at all

g. Other (please specify) ………………...

6. How many times did you get out of your bed after going to sleep?

a. 1

b. 2

c. 3 or more

d. I did not get out of my bed

7. If you used restroom after wearing the hip protector, did you take the hip protector off?

a. Yes

b. No

c. I did not get up in the middle of my sleep to use the restroom

8. Did you have to adjust the waist band during the night?

a. Yes

b. No

9. Did you have to adjust the thigh band during the night?

a. Yes

b. No

Following the scale below, please indicate your level of comfort by circling the appropriate number after the question. Please refer to the sketch if you need clarification about the area mentioned in any question.

100 ------------ Greatest Imaginable Comfort

80 ------------ Extremely Comfortable

60 ------------ Very Comfortable

40 ------------ Moderately Comfortable

20 ------------ Slightly Comfortable

0 ------------ Neither Comfortable nor Uncomfortable

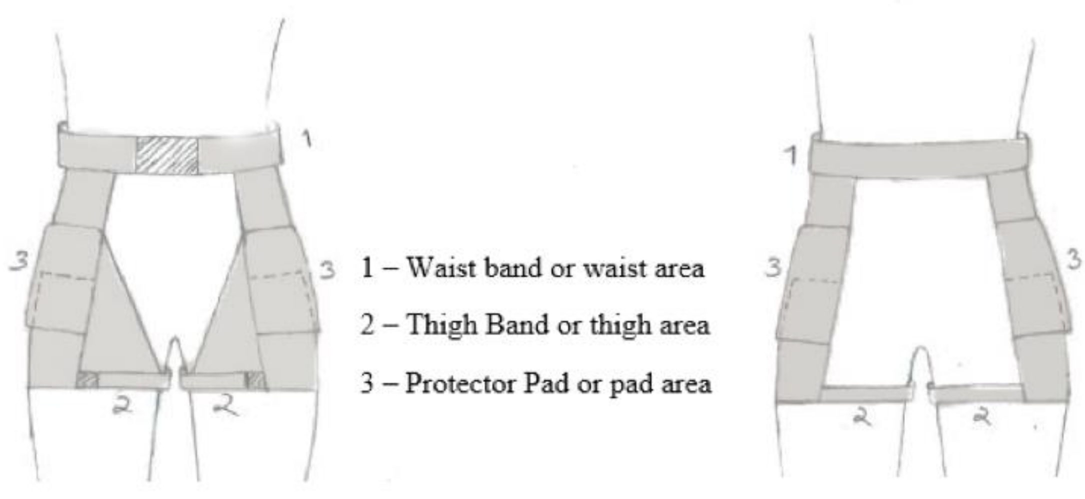
-20 ------------ Slightly Uncomfortable

-40 ------------ Moderately Uncomfortable

-60 ------------ Very Uncomfortable

-80 ------------ Extremely Uncomfortable

-100------------ Greatest Imaginable Discomfort



Front View

Back View

1. Feeling about putting on the hip protector to get ready to sleep	100	80	60	40	20	0	-20	-40	-60	-80	-100
2. Feeling about your look after wearing the hip protector	100	80	60	40	20	0	-20	-40	-60	-80	-100
3. Feeling about your movements while you were lying down wearing the hip protector	100	80	60	40	20	0	-20	-40	-60	-80	-100
4. Feeling about your sleeping position while wearing the hip protector	100	80	60	40	20	0	-20	-40	-60	-80	-100
5. Feeling about the material/fabric of the hip protector against your skin	100	80	60	40	20	0	-20	-40	-60	-80	-100
6. Feeling about falling asleep while wearing the hip protector	100	80	60	40	20	0	-20	-40	-60	-80	-100
7. Feeling in terms of body temperature while wearing the hip protector	100	80	60	40	20	0	-20	-40	-60	-80	-100
8. Feeling about overall weight of the hip protector	100	80	60	40	20	0	-20	-40	-60	-80	-100
9. Feeling about the design of the hip protector	100	80	60	40	20	0	-20	-40	-60	-80	-100
10. Feeling about the waist band of the hip protector being adjustable	100	80	60	40	20	0	-20	-40	-60	-80	-100
11. Feeling about the thigh band of the hip protector being adjustable	100	80	60	40	20	0	-20	-40	-60	-80	-100
12. Feeling about taking off the hip protector	100	80	60	40	20	0	-20	-40	-60	-80	-100

13. Overall feeling about the hip protector	100	80	60	40	20	0	-20	-40	-60	-80	-100

Appendix C

Post Overnight Interview Questionnaire

Subject number:

Post overnight wear test interview

1. Describe your experience about putting the hip protector on?
2. Describe your experience about taking the hip protector off?
3. Describe your last night sleep wearing the hip protector?
4. How did you feel about falling asleep wearing the hip protector?
5. Did you wake up in the night after falling asleep? If so, please describe your experience. Did any particular aspect of the hip protector affect your sleep?
6. Did any particular aspect of the hip protector affect your movement while lying down?
7. Describe your feelings about having protector pads on both sides of your hips?
8. Describe any part of the wear test you found stressful?
9. Describe your thoughts about the position of closure at your thigh band?
10. Describe your feelings about hand of the fabric against your skin? If you wore the hip protector on top another garment, how did the fabric of the hip protector feel when you touch it?
11. How would you recommend to improve the design of the hip protector?

Appendix D

IRB Approval

Oklahoma State University Institutional Review Board

Date:	Monday, February 15, 2016
IRB Application No	HE1583
Proposal Title:	Designing of Hip Protectors for Elderly Women
Reviewed and Processed as:	Expedited

Status Recommended by Reviewer(s): Approved Protocol Expires: 2/14/2017

Principal Investigator(s):

Mostakim Imran Ahmed Tanjil	Mary Ruppert-Stroescu
201 HSCI	431 Human Sciences
Stillwater, OK 74078	Stillwater, OK 74078

The IRB application referenced above has been approved. It is the judgment of the reviewers that the rights and welfare of individuals who may be asked to participate in this study will be respected, and that the research will be conducted in a manner consistent with the IRB requirements as outlined in section 45 CFR 46.

☒ The final versions of any printed recruitment, consent and assent documents bearing the IRB approval stamp are attached to this letter. These are the versions that must be used during the study.

As Principal Investigator, it is your responsibility to do the following:

1.Conduct this study exactly as it has been approved. Any modifications to the research protocol must be submitted with the appropriate signatures for IRB approval. Protocol modifications requiring approval may include changes to the title, PI advisor, funding status or sponsor, subject population composition or size, recruitment, inclusion/exclusion criteria, research site, research procedures and consent/assent process or forms
2.Submit a request for continuation if the study extends beyond the approval period. This continuation must receive IRB review and approval before the research can continue.
3.Report any adverse events to the IRB Chair promptly. Adverse events are those which are unanticipated and impact the subjects during the course of the research; and
4.Notify the IRB office in writing when your research project is complete.

Please note that approved protocols are subject to monitoring by the IRB and that the IRB office has the authority to inspect research records associated with this protocol at any time. If you have questions about the IRB procedures or need any assistance from the Board, please contact Dawnett Watkins 219 Scott Hall (phone: 405-744-5700, dawnett.watkins@okstate.edu).

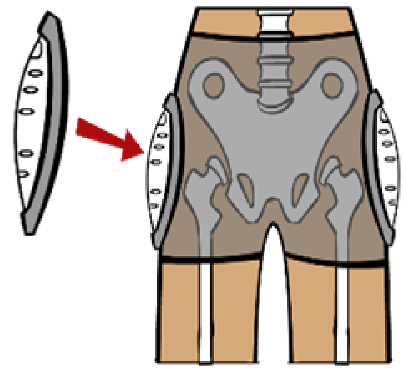
Sincerely,

Hugh Crethar, Chair
Institutional Review Board

Appendix E

Recruitment Email

Come Join Us for our study "designing hip protectors"



We developed a hip protector prototype and we need your feedback about comfort of the prototype

Who: Women

- age 60 years or over
- Waist 33 to 37 inch

When: January 20, 2016 – March 10, 2016

How: Wear a hip protector prototype overnight at your place

Interested?

Please contact Mostakim Tanjil at

313-603-1678 or imran.tanjil@okstate.edu

Appendix F

Consent Form

PROJECT TITLE: Designing of hip protectors for elderly women

INVESTIGATORS:

Mostakim Tanjil, Master's student in Oklahoma State University. Dr. Mary Ruppert-Stroescu, Assistant Professor at Oklahoma State University.

You agreed to take part in the research study "Designing of hip protector for elderly women" and you meet our inclusion criteria: a) age 60 years or over, b) waist 33 – 37 inch, c) ambulant with or without assisted devices – you can walk, move, change clothing and use restrooms without human assistance, d) you do not have cognitive disorders, and e) you are not under prescribed psychotropic and sedative medications. This study has been approved for human subject participation by the Oklahoma State University Institutional Review Board. This form explains the research study in detail. Please read it carefully and ask the researcher to explain anything you do not understand.

PURPOSE:

The primary purpose of this study is to understand comfort issues associated with wearing newly developed hip protector prototype. We will also determine the level of acceptability of the hip protector prototype by the users. In addition, the findings of the study will also contribute to design modification for future hip protector development.

PROCEDURES

If you take part in the study, you will be assigned an ID number and asked to wear the hip protector. In this study, there are two meeting sessions of 30 minutes each and an overnight wear test. For the first meeting, we ask you to come to HSCI 201. Upon your arrival, the researcher will give you the hip protector, show you the proper way of wearing it and how to adjust the waist band and thigh band. Then you will wear it as directed and perform the following activities, once, at your normal pace: i) standing to sitting on the provided chair ii) sitting to standing iii) sitting for five minutes on the provided chair iv) sitting to lying on the provided bed v) lying to sitting and vi) walking for 10 meter, and subsequently fill out the first questionnaire. Then we ask you to take the hip protector to your place of residence and sleep in your regular position wearing the hip protector overnight (at least 6 hours). After going to bed, you can get up and do necessary activities such as using restroom, get a glass of water etc. However, we ask you not to take the hip protector off, and if you need to take it off, we ask you to put it on as soon as necessities are over. The next morning you will fill out the second questionnaire as soon as it is convenient for you after you get up. We will meet you to conduct the exit interview at a place convenient to you and retrieve the hip protector.

RISKS OF PARTICIPATION:

There are no known risks associated with this project which are greater than those ordinarily encountered in daily life. However, there may be discomfort due to pressure on flesh around waist and thigh area. Both waist and thigh bands of the hip protector are adjustable, and you can adjust pressure and make them comfortable. You might feel slightly uncomfortable because of the pads attached on both sides of the hip protector. The pads are made of foam and will not dig into your flesh. The pads will not cause any harm to your flesh or bones. In case of injury or illness resulting from this study, we will not provide emergency medical treatment. No funds have been set aside by Oklahoma State University to compensate you in the event of illness or injury.

BENEFITS OF PARTICIPATION:

There is no direct benefit to you for participating in this study.

Hip protectors are protective garment to prevent hip fracture during falls. However, because of design problems of hip protector, adherence rate to wearing hip protector is very low. Therefore, a prototype is developed addressing people's physiological and psychological needs. Your perception and comfort issues related to wearing the prototype will help us modify our design further.

CONFIDENTIALITY:

No personal identifiable information will be collected and only the researchers will have access to the information collected. The questionnaire data will be stored and secured at Dr. Ruppert-Stroescu's office (438 Human Sciences) in a locked file cabinet for 1 year. Information stored in the password protected laptop for analysis will be discarded by the end of April 2016. The results of this study may be published or presented at professional meetings but the identities of the research participants will remain anonymous. No published results will identify you, and your name will not be associated with the findings.

COMPENSATION:

There is no monetary compensation for participating in this study.

CONTACTS:

You may contact any of the researchers at the following addresses and phone numbers, should you desire to discuss your participation in the study and/or request information about the results of the study:

- Mostakim Tanjil, Dept. of Design, Housing and Merchandising, Oklahoma State University, Stillwater, OK 74078, 313-603-1678

- Dr. Mary Rupert-Stroescu, 438 Human Sciences Bldg., Oklahoma State University, Stillwater, OK 74078, 405 -744 -5035

If you have questions about your rights as a research volunteer, you may contact the IRB Office at 223 Scott Hall, Stillwater, OK 74078, 405-744-3377 or irb@okstate.edu

PARTICIPANT RIGHTS:

I understand that my participation is voluntary, that there is no penalty for refusal to participate, and that I am free to withdraw my consent and participation in this project at any time, without penalty.

CONSENT DOCUMENTATION:

I have been fully informed about the procedures listed here. I am aware of what I will be asked to do and of the benefits of my participation. I also understand the following statements:

I affirm that I am 18 years of age or older.

I have read and fully understand this consent form. I sign it freely and voluntarily. A copy of this form will be given to me. I hereby give permission for my participation in this study.

__________________________ __________________________

Signature of Participant Date

I certify that I have personally explained this document before requesting that the participant sign it.

__________________________ __________________________

Signature of Researcher Date

VITA

Mostakim Imran Ahmed Tanjil

Candidate for the Degree of

Master of Science

Thesis: DESIGNING OF HIP PROTECTORS FOR ELDERLY WOMEN

Major Field: Design, Housing and Merchandising

Biographical:

Education:

Completed the requirements for the Master of Science in Design, Housing and Merchandising at Oklahoma State University, Stillwater, Oklahoma in May, 2016.

Completed the requirements for the Bachelor of Science in Textile Technology at College of Textile Technology, University of Dhaka, Dhaka, Bangladesh in 2008.

Experience:

Analyst, Center for Health Systems Innovation, Oklahoma State University.
Graduate Research Assistant, Dept. of Design, Housing and Merchandising, Oklahoma State University.
Graduate Teaching Assistant for Textiles (DHM 2573), Design, Housing and Merchandising, Oklahoma State University.