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RESEARCH ARTICLE

Using a human centred design approach to develop a fall detection sock for older women

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ABSTRACT

This work focuses on using a human centred design approach for the creation of electronic textiles with monitoring capabilities for use by older women. This study specifically looked at the creation of a system for fall detection, as falls can be a serious issue for older adults. Beyond this, the study also strove to understand older women's views on clothing, technology and falls more generally. Twelve women aged 65 and over were first asked to participate in semi-structured interviews. From this initial insight, prototype garments were produced and a workshop with five women was held to gain deeper feedback and refine the design. This work has shown that when designing electronic textiles for older women, key factors include comfort, easy-care clothing, flexibility in clothing choice, and the technology being invisible when worn. This also acts as an important case study for human centred design with electronic textiles for older women.

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Design; human centred design; older adults; electronic textiles; smart textiles; fall detection

Introduction

This study focused on understanding the needs of older women (65+) when designing assistive electronic textile (E-textile) devices for them. Specifically in this work fall and near-fall detection was the targeted application given the serious impact that falls can have on the ability of older adults to live independently (Cumming et al. 2000). The focus was on women as women fall more than men (Gale, Cooper, and Aihie Sayer 2016), and traditionally women in health-related studies/trials have been ignored and even when designing gender-neutral products women are an afterthought (Criado-Perez 2019). Further, designing clothing for women as they age is incredibly complex (Twigg 2013): It has been observed that there is an issue around finding age-appropriate yet flattering clothing. This is echoed in a study conducted

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to look at designing womenswear more effectively to meet the physical and emotional needs of older women (Townsend, Sissons, and Sadkowska 2017). This study found that older women are aware of fashion, but they need their body features to be considered to ensure proper sizing and fit (Townsend, Sissons, and Sadkowska 2017). This study also highlights the importance of using a human-centred design (HCD) approach to ensure that the needs of the people that are being designed for are taken into consideration.

It was important to the authors to design an E-textile that older women were willing to wear as most previous studies focus on technical considerations only, ignoring user experience. As a result, this study contributes much needed insight into what older women, would or would not be willing to wear to monitor their risk of a fall, the perception of need and the aesthetics.

Falls can be incredibly detrimental to the quality of life of older adults. Hip fractures are a common injury from a fall (Iolascon et al. 2013) and occur more frequently in women as they are more likely to have osteoporosis (Age UK 2019; Lorentzon et al. 2022). After a hip fracture, only 36% of older adults go back to independent living (Tang et al. 2017), there is a 27% morbidity rate (Vaishya and Vaish 2020) and people are left with a fear of falling (often from being left alone on the floor for over an hour (Bagalà et al. 2012)). Fear of falls can result in more falls because people are less mobile, and a decrease in mobility causes frailty, which is a risk factor for falling (Ambrose, Paul, and Hausdorff 2013). Additionally, falls are very costly to social care services (for example, they cost the UK's NHS more than £2.3 billion per year). Therefore, the ability to detect falls will help with the long lie but to prevent falls, it would be best to detect near-falls. Near-falls are defined in literature as *'slips, trips, stumbles, missteps, incorrect weight transfer, or temporary loss of balance'* (Pang et al. 2019). The more near-falls a person experiences, the higher the risk of a fall.

It has been observed that little attention is paid to the needs, wants and preferences of older adults while developing fall detection systems, as demonstrated in a scoping review from 2016 (Thilo et al. 2016), which appears to be the most recent review on the topic. The review emphasizes the need to involve older adults earlier in the process (conception and design), which will aid in the uptake and correct usage of these systems. The authors of the review have gone on to conduct a study that involved older adults in the design stage of developing a wearable fall detection system (Thilo et al. 2017). To the knowledge of the authors, the main focus of fall detection and near-fall detection studies continues to be on the technical design and accuracy rather than the wearability of the system. Although this is crucial, the studies have not considered where the sensors are located. For example, in some studies, a sensor was placed on the head (Özdemir and Barshan 2014; Wu et al. 2019), which this study found to be unacceptable to the user group of older women. This study has combined research on the

ideal position of the sensor for near-fall detection (waist, thigh, or ankle (Ntanasis et al. 2017; Rahemtulla et al. 2021)), with the insights of older women on their clothing preferences, attitudes towards technology and monitoring systems to design solutions that would be acceptable to the target user group.

To understand the needs and preferences of older women, a HCD approach was used. HCD focuses on the needs and wants of the users along with their experiences (Giacomin 2015). Further, an E-textile based device was chosen for this study as E-textiles are a perfect wearable substrate for integrating a fall (or near-fall) sensing system as they can be made to be discrete and are comfortable to wear against the skin. Within the field of E-textiles, various innovations have been developed for older adults however very little work has been conducted where co-design or HCD principles have been applied. Researchers (Salisbury, McGinley, and Ozden Yenigun 2023; Wang, Yang, and Yin 2023) in E-textiles have discussed the benefits of working with end users. Further, there has typically been a lack of collaboration between the different disciplines required to develop monitoring devices for older adults, with a notable exception being the MATUROLIFE project (Callari et al. 2019; Yang and Moody 2022).

The resultant device designed from this study has been trialled extensively and the technology proven (Rahemtulla et al. 2023). However, the previously published work focuses on the technical aspects of the device and not the extensive design considerations given to its form. The article outlines how an understanding of the end user need was determined, and how the final device design was determined. This study partially follows previous investigations into older women's clothing preferences (Twigg 2013; Townsend, Sissons, and Sadkowska 2017), however in this case the work has a targeted focus on the design of E-textile prototypes for near-fall and fall detection.

Aim and objectives

This study aimed to design an E-textile garment that older women would be willing to wear. The specific focus was on creating a garment for fall and near-fall detection. This study investigated the perceptions of older women on clothing preferences, attitudes towards technology, ideas on wearable technology and placement. Participants were also asked more specific questions on fall prevention and placement of sensors. The objectives were to:

- Understand how open older women would be to wearing an E-textile garment for fall and near-fall monitoring, and to wearables for health more generally.
- Establish the design considerations required by the older women, without forfeiting the accuracy of the E-textile.

- Create prototypes based on older women's opinions and determine what is desirable.

Materials and methods

Interviews

Twelve women were recruited using the snowball sampling method (a common method for qualitative research (Parker, Scott, and Geddes 2019)). Each participant was given an information sheet about the study and signed a consent form. The age ranges of the women are shown in Figure 1. Ethical approval (protocol code 2021/22-28) was granted by the Nottingham Trent University College of Art, Architecture, Design and Humanities (CAADH) Research Ethics Committee in December 2021. Informed consent was obtained from all participants.

The interview explored four key topics; clothing preferences; current and future health needs; attitude towards technology including wearable, health and monitoring devices and falls, fall prevention and fall detection. There were 28 questions in the interview schedule and the semi-structured interviews lasted approximately 30 – 45 minutes. The interviews took place on Microsoft Teams (Microsoft Corporation, Redmond, WA, USA), and videos of the interviews were recorded and transcribed by the software; the transcripts were subsequently checked and corrected. Once an accurate transcript had been recorded the videos of the interviews were deleted. Each participant is referred to using the code F, for female, and a number. The interview data was analysed using thematic analysis and coding was conducted using NVivo (v.12 Pro for Windows, ©QSR International, Burlington, MA, USA). The interview data also contained information that was analysed quantitatively when binary questions were asked. The authors are aware that the information from these interviews is not statistically representative due to the sample size.

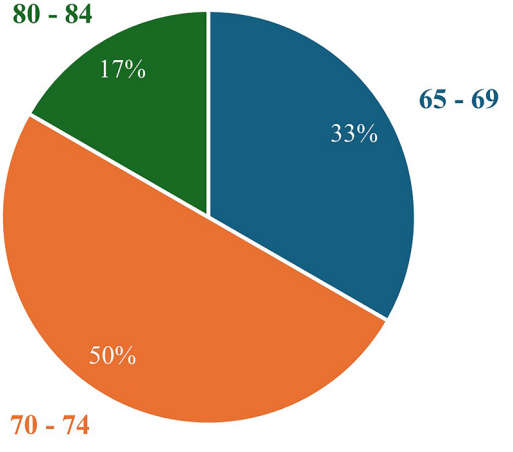

Figure 1. Chart showing the age of the female participants.

Prototype development

From the outset, the project was set to use electronic yarn (E-yarn) technology to integrate the sensing element into the prototypes. This technology allows any small-scale component to be incorporated within the structure of a textile yarn while retaining normal properties such as drape and softness; the technology has been used in various sensing devices (for example a gait monitoring sock (Lugoda et al. 2022)). The supporting hardware for the control of the sensor, transmission of data, and power, was to take the form of a small, detachable hardware module. For the prototypes, the supporting hardware was simulated using appropriately sized, small pieces of acrylic.

The project team already knew the best sensor locations for fall detection from a technical standpoint (Ntanasis et al. 2017; Rahemtulla et al. 2021). This knowledge was presented in one of the interview questions and the response to this and other questions were used to develop three fall detection E-textile prototypes: These took the form of an anklet (sensor on the ankle), shorts (sensor on the thigh), and patch (sensor on the waist).

The ankle and shorts prototypes were seamlessly knitted with an integrated channel for the insertion of the E-yarn sensor and a pocket to accommodate a supporting hardware module using a Stoll CMS ADF 32W E7.2 (Lengede, Germany). Both prototype's main bodies used a knitted single jersey structure. The ankle prototype was made of three yarns: Stretchline black Lycra 16/SCY/090 and 20/DCY/003, as well as Nylon 6 70/68/2 in black. The yarns used in the shorts prototype included Nylon 6/6 2/78/68 in white, Zimmermann Ultralastic 5879XX-0301 and Stretchline white Lycra 16/SCY/090. The patch prototype was made using cut and sew techniques from cotton and polyester.

Focus group

Five women attended an in-person focus group: This included four participants from the interviews. During the focus group, each prototype was discussed individually, followed by a discussion around aesthetics to help participants envisage what appearance the proposed designs could have. The audio from the focus group was recorded, and each of the three facilitators made notes during and directly after the session. The recording was transcribed, and thematic analysis was performed on the data, as for the interview data.

To ensure that all the participant's opinions were captured a questionnaire was given at the end asking the participants to numerically rate the three prototypes according to comfort, sustainability, practicality, ease of use, durability, appearance, materials, features, feel and overall design from 1 – 5, with 5 being the most positive. They were also given space to justify these choices. In addition, they were asked to rank the prototypes from 1-3, with 3 being the favourite.

Results

Interview data

Clothing preferences

Three important themes were found when exploring people's attitudes towards clothing: physical comfort, emotional comfort, and quality. Emotional comfort and physical comfort are intimately linked and were often mentioned within the same sentence. *Comfort*. The word comfortable was used multiple times by ten of the participants as a clothing priority. Participants were not only concerned about physical comfort but also emotional comfort. Emotional comfort means wearing something flattering, stylish, age-appropriate and appropriate for the context in which it is to be worn. F2 was direct in connecting tightness with comfort by saying,

> I don't tend to go for anything too tightly fitting, again, cause of comfort.

Although each participant expressed a range of individual clothing preferences, when asked about the preferred fit of clothing, tight-fitting clothing was not wanted, especially when it was tight around the waist; for some, this was primarily linked to health issues and physical comfort, as indicated by F3.

> I've really gone off tight fitting clothing. […] I quite like having narrower trousers. With a long top over the top, but again, anything that really cuts into my waist, it just sets off digestive problems…

For others, it was emotional comfort and wanting to hide perceived undesirable parts of themselves as indicated by F1:

> I don't want to wear things that are so tight that they show every little bulge.

Although tight fitting clothing was considered undesirable, nine of the participants stated they wore some form of stretch fitted garment, either stretch jeans, jumpers, leggings or thermal layers.

In addition to being comfortable and to not wanting tight fitting clothes, it was clear that people still want to look their best. F3:

> I want things to be comfortable. I want them to look good and be flattering as far as possible.

Age-appropriate clothing. Many of the participants discussed the perceived age appropriateness of different clothing. F9 said:

> I don't like to choose something to wear that I think it makes me look as if I want to be wearing something too young for me […]. I want to wear something that is suitable but trendy and comfortable…. I like to seem to be sensible for my age. But not looking old fashioned and dreary.

For this generation, it appears that finding age-appropriate clothing is an issue with F1 saying:

> I think actually for our age group finding nice clothes that don't make you look like mutton dressed as lamb and yet don't make you look ancient is quite an issue.

This area of difficulty expressed by the women in this study was shared with the group of women who took part in the Emotional Fit project (Townsend, Sissons, and Sadkowska 2017).

Difficulties with clothing. When asked about clothing difficulties a third of the women experienced issues affecting their hands. Women are more likely than men to develop arthritis as they age (Petrovská et al. 2021). A third of the women expressed lower body difficulties and the final third had no difficulties. These clothing difficulties affect the types of clothing that people are willing to buy. F8 had reduced dexterity from an old injury making the use of zips and buttons hard. She said:

> …the difficulties I have sometimes are doing up zips […] and also I mean sometimes buttons.

Washing of clothing. When discussing the properties of clothing, washing habits were mentioned by some participants. While the proposed E-textile system would be machine washable, washing is an intense chemical and mechanical process and would lead to failures given time. It was clear that using the washing machine was the preferred method for cleaning clothes. F6 said she would:

> …never buy anything that says hand-wash, everything needs to go in the washing machine.

In a similar vein both F9 and F10 avoid clothes that ask for dry-clean only. Essentially, the clothes that can be washed in the machine are easier to care for and preferred by the participants rather than dry cleaning or hand washing. The participants were not asked how they dry their clothes, which would also be a consideration for the design of any E-textile that is meant to be washed.

Technology

Attitudes towards technology were explored to gauge how comfortable people are using technology and integrating it into their daily lives. As the interviews were performed online there was a bias, as all the participants had the technical competence to participate in a teleconference. For the most part, the participants liked technology, but they found it hard to use and needed

help from another person. F12 clearly communicated her anxiety about technology saying:

> I'm afraid of it.

Two people had similar opinions on the usefulness of technology but with different attitudes to technology itself. F7 was more positive:

> Technology is good, but I'm not very good with technology

F3 said:

> I just view it as a necessity, but I don't take any pleasure in it.

Another interesting attitude was similarly mixed, with F2 saying:

> I'm for it as long as it's beneficial. I do not wish to be looking at my watch all day to be seeing how many steps I've done.

Only three participants owned wearable technology, in all cases this took the form of a smart watch. Several participants acknowledged that owning wearable technology can induce obsessive behaviour. F1 stated:

> We had a Fitbit which I was actually a bit obsessed with really. You know, I've got to do so many steps every day.

By contrast, six of the twelve participants own some form of health-monitoring device. The COVID-19 pandemic caused two participants to invest in these types of devices. F5 clearly stated:

> …because of COVID, we've got an oxygen meter.

When asked about the location where they would be willing to wear technology, the overwhelming majority said the wrist and liked the idea of a watch or jewellery. In addition, the neck came up in the form of a necklace; however, when asked where they are not willing to wear technology, the neck was also mentioned. The responses for where they would not be willing to wear technology were much more varied. There was a resignation to wearing a device if it was compulsory for health needs. F1 said:

> If it was something that was very important from a health point of view, then you would just have to accept it and wear it where you had to wear it wouldn't you. Don't think I would be over fussy about that, if it was for a medical reason.

Falls

When discussing falls most participants did not currently have mobility, stability, or movement issues. However, that does not mean that the prospect of a fall was not a concern. There was an understanding that once you reach a certain age and have a fall the effects can be devastating. Some of the

participants talked about older people they know, care for or have cared for, which is why they worry about falls, but they do not see themselves as being in an at-risk category yet. F1 said:

> I can think of several instances of elderly people, and when I say elderly a lot older than me elderly, who've had falls, in some cases, become a fatality in the end because it's been such a shock to their system.

There does appear to be a distinction between being an older adult and being elderly, which is clear in the quotes above. When asked about wearing an alarm to call for assistance following a fall, F2 said:

> …not now but if I was much older than I am, yes, definitely.

This sentiment was shared by other participants. F4 talked about falls becoming more of a concern as you age, while F9 talked about how as people age, they tend to ignore problems:

> Old people become really proud, and they don't, you know, realise that they're not as good as they used to be with their movements and so on…

F9 is 82, so statically a fall is incredibly dangerous for her as well, half of over 80s will fall at least once in the year ('Falls - NHS' 2024). F6 was also concerned about falls and differentiated between a younger person falling compared with an older person.

> The biggest concern about being older is that if you're younger and you fall, people say you've fallen over. If you're older and you fall, people say, oh, she's had a fall, as if it's an entirely different thing.

Yet F6 would not be willing to wear a device that calls for assistance. The idea of being seen as or accepting oneself as being sufficiently old to be at risk of a fall was not at all appealing to the participants.

Wearable electronic textile design

Participants were asked how they felt about wearable technology being visible or concealed (Figure 2(a)) and whether they would prefer wearable technology to be part of a garment or attachable to an item of clothing (Figure 2(b)). None of the participants actively wanted anything visible unless it was something to show off, like a Fitbit or jewellery. Additionally, most people wanted it to be attachable so that it did not interfere with what they want to wear, to avoid the cost of buying multiple E-textile items, and for washability.

It seemed that many of the participants were envisioning something like a smartwatch or smartphone attached to their body. This clearly influenced their responses, particularly when discussing specific locations on the body

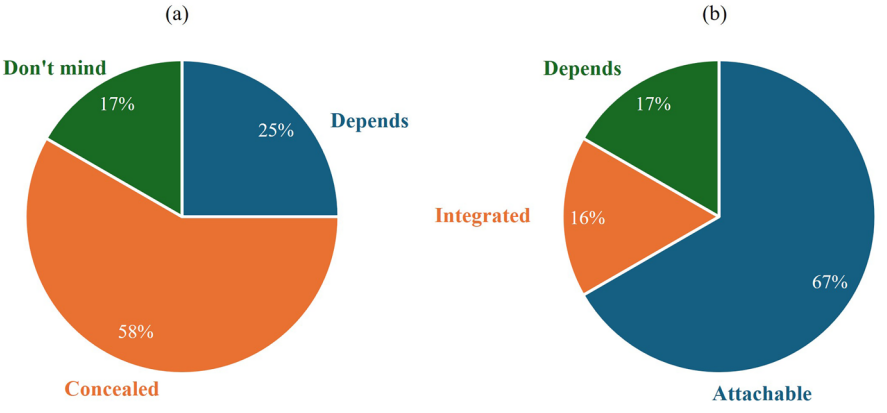

Figure 2. Charts showing the preferences of the participants. Twelve people were interviewed. Percentages are included for ease of interpretation. (a) Whether the participants would prefer the electronics to be concealed or visible. (b) Preferred integration technique for the electronics.

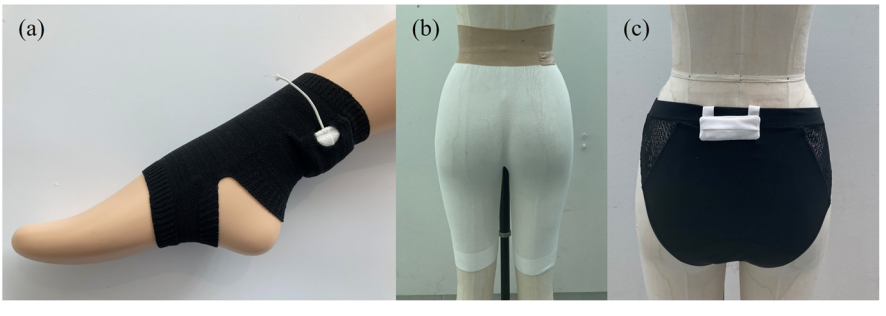

Figure 3. Prototypes. (a) Ankle prototype. (b) Shorts. (c) Patch attached to commercial underwear.

(ankle, thigh or waist) for near-fall detection. Of the three given locations, the waist was the most popular choice, while the thigh was the least popular. When discussing the ankle, it seemed people were imagining an ankle tag like those worn by individuals under house arrest.

Prototype development

The information collected from the interviews was thematically analysed and used to develop the three prototypes: an ankle prototype (Figure 3(a)), shorts (Figure 3(b)) and a patch (Figure 3(c)). These were non-functional prototypes but replicated approximately what a functional fall detection E-textile could look and feel like.

Important aspects of the prototypes' design were that they should be comfortable, concealable, and possibly have the electronics be attachable rather than integrated into a garment. As stretch clothing was mentioned by

several participants, this was incorporated into the designs. To accommodate the desire for something that could be concealed and attached, and that would not limit an individual's daily garment choices, the prototypes developed were accessories, undergarments, or a patch that could be attached to a garment.

As quality and value for money were of interest to the participants, and the team aimed to make a long-lasting product, the ankle prototype was created to eliminate the parts of a sock that tend to wear through first, namely the heels and toe. It also potentially limited the need for washing as it could be worn over socks.

For the ankle prototype, the E-yarn sensor was positioned in a channel that ended below the ankle bone while the rest of the electronics were in a module at the back of the ankle intended not to inhibit movement and to be out of the way of shoes. The shorts were inspired by anti-chafe shorts that are commercially available. In this design, the main electronics module was positioned on the waist and the sensor was on the upper thigh/hip. The third prototype (patch) was designed to incorporate all the electronics as a fully attachable/detachable textile piece. For the focus group, the patch was attached to commercially available underwear using snap fasteners.

Focus group data

Ankle prototype

The views of the participants on the ankle prototype were varied. On first appearance, F6 clearly stated:

> I wouldn't wear it.

However, as the conversation continued, she said that she:

> …might wear it in the winter.

As the focus group was held during hot weather, this seemed to influence people's responses as their concern was linked to emotional comfort and they did not want to be seen wearing something on their ankle if their legs were exposed. However, the participants did state that the ankle prototype would be the most comfortable of the three designs at night. The majority thought that a fall prevention device would be most needed in the daytime, with F12 saying:

> …the risks are greater during the day.

This is not necessarily the case, as falls tend to occur at night in the bathroom (Kerchner 2019). There was a general agreement that owning multiple

socks would be useful, as it would allow for different colours, and would facilitate washing.

Unlike most of the participants, F12 would be willing to wear the ankle prototype if it was commercialized as she had health issues where having a fall could be particularly detrimental, and this made her more receptive to wearing a fall detection device. She also gave some design suggestions, such as a longer sock so the hardware module can sit above a boot. When the participants were touching the device and taking the (mock) hardware module out of the pocket, it was mentioned by F13 that getting the hardware module in and out was *'a fiddle'.* This could be easily improved in future iterations of the design.

Shorts prototype

Similar to the ankle prototype, the shorts prototype solicited mixed reactions. Many participants could not see past the design flaws in the prototype in front of them, rather than them seeing the prototype as a first iteration. Even so, there were positive attitudes towards the shorts. Comments by F3 included:

> I do wear short leggings under dresses, and I find it really comfortable and …to me it's like wearing sort of a slip but it works properly.

In addition, there were conversations about changing the design to suit them. They talked about having the waist higher or lower, as well as less thick or tight. The waist height was selected by the design team based on wear testing. The team were aged under 40 so the participants' assessment indicates that it would have been beneficial to undertake a co-design process to include the perspective of women over 65 throughout the design process for the prototypes. The authors are aware that in the current colour, when not worn, they look like and were described by the participants as bloomers (used here in a derogatory manner). F3 stated:

> I'd definitely consider wearing things like the shorts if they were more comfortable and more trendy and not like granny bloomers.

The shorts could be adapted to meet the participants' requests. Further, while discussing altering the design of the shorts prototype, there was a conversation about underwear, with the group discussing putting the electronics into a pocket in underwear.

Patch prototype

When shown the patch, although it was explained that the patch could only be placed at specific points on the body for accurate detection, the device was seen as attachable anywhere and therefore the participants were more

enthused about this prototype. One participant wanted to put it inside her bra, which would not give accurate data. F6 said:

> I'd want that on my outer clothes. I'd want it on my trousers or my skirt or something I wouldn't want it on under because you want to put other clothes on. I'd want that to be the last thing I was wearing.

If it was attached to a waistband, positioning the patch on an outer garment could be entirely compatible with accurate data collection. The only apparent disadvantage to the patch expressed by the participants was the snap fasteners used to attach it to the fabric. F4 said they were:

> …a bit fiddly.

What the preference for the patch prototype showed was the extent to which the group valued having control over their garment choices.

Questionnaire

The results of the questionnaire held at the end of the focus group supported the opinions expressed during earlier discussions (the full results from the questionnaire can be found in the supplementary data). Each prototype was ranked based on comfort, ease of use, practicality, durability, appearance etc. From this in-depth ranking, the patch was seen to be the preferred option, followed by the ankle prototype, with the least favourite prototype being the shorts. However, when asked to rate the prototypes in order of preference, while the patch remained the most popular option the least favourite became the ankle prototype. This indicated that the difference in preference between the ankle prototype and shorts was minimal.

The reason for conducting the focus group was not to obtain a definitive result as with only five participants the marginal differences in preference between the three prototypes need to be treated with caution. The sample size is not of statistical significance and a larger group may have produced a different result. Much of the data from the interviews and previous studies of the clothing preferences of older women, or people in general, shows that there were always likely to be diverse opinions reflecting the participants' different body shapes, ailments, insecurities, identities, and the image an individual wishes to cultivate and project. Importantly, none of the prototypes were wholly discounted and participants envisaged using different ones according to the circumstance, for example, the ankle prototype at night and the shorts when wearing a dress. This outcome means further research would be required if the aim was to commercially produce one item.

Discussion

The interviews and focus group showed that falls were a concern for most of the women; however, there was a reluctance to admit that they were at risk,

unless they already have an underlying condition. Despite several participants being in their 70s and above, most did not perceive themselves to need the technology yet. Although they know they are older, they do not see themselves as elderly. Therefore, to get them to accept monitoring technology, there must be perceived need, ease of use and benefit, factors which are known to be key to technology acceptance (Peek et al. 2014). This is also in agreement with other studies that investigate the use of wearables by older adults (Moore et al. 2021; Kim and Choudhury 2020).

Within the focus group, this was explored further, and the suggestion was that the technology should be recommended by medical practitioners, physiotherapists, or chiropractors. One study has shown that older adults are more likely to use assistive technology if recommended by a paid caregiver rather than an unpaid caregiver (Dahlke et al. 2021). However, this reinforces the idea that they are too old and are being forced to wear these devices.

To combat the stigma associated with assistive technologies, the design of the device is incredibly important. Designers and technologists need to collaborate to educate intended users and create devices that can fit into people's lifestyles. In this study, comfort was the participants' most frequently cited priority when choosing clothes, and there was an inclination towards looser-fitting garments. Other preferences were the ability to wash clothing in a washing machine easily and the use of natural fibres along with stretch.

The three prototypes were designed to align with the identified preference for comfortable, easy-care clothing, while allowing flexibility in clothing choice, and to be invisible when worn. Additionally, the prototypes were designed primarily as accessories, as participants did not want the technology to dictate their outfit choices.

Contrary to the perception that seamless integration should be the priority when designing E-textiles (Meena et al. 2023), participants were concerned that integrated technology would limit their clothing choices and oblige them to own multiple identical items. This is an important outcome that must be considered when developing E-textiles for older adults in the future.

Although overcoming technical challenges is important, E-textile developers need to bear in mind both older people's physical needs and the role clothes play in self-expression and social signalling. Otherwise, technical accomplishments may be in vain, due to a lack of user acceptance. This study has reinforced that these factors become increasingly complex for women as they age, with aliments dictating what is comfortable, the desire to hide their perceived imperfections, and endeavouring to neither appear too old nor too young (Townsend, Sissons, and Sadkowska 2017; Twigg 2013).

The three prototypes made all had advantages and disadvantages, with the biggest disadvantage being the current bulk of the electronics module which was, in this first iteration, fiddly to attach and detach. The participants expressed interest in owning several of the proposed prototypes so they

could wear them according to how they felt, what they would be doing, and how they were dressed in much the same way as they would for the rest of their clothing. The ankle prototype was chosen to be developed into a functioning E-textile and has been shown to accurately differentiate between falls, near falls and activities of daily living (Rahemtulla et al. 2023).

Conclusion

This study shows that falls are a concern for older women, and they are open to wearing an E-textile garment for fall and near-fall detection. However, while they are still mobile, participants felt an insufficient need for a monitoring device to warrant wearing a specific piece of technology. There is a stigma around ageing that was too great to overcome in this study. They would rather wait for a problem than prevent the problem from occurring. As a result, one of the proposed ways they would be willing to wear a monitoring device would be if it were a risk assessment tool used by healthcare professionals.

When designing wearables for older women, the most important consideration is comfort. Each participant's clothing preferences were varied; therefore, the prototypes were made as accessories to be worn under or over garments. The hardware to control the E-yarn with the embedded sensor was designed to be detachable to address the concerns around the need to own multiple items and washability. Further, the E-yarn itself has been placed in a knitted channel allowing it to easily be removed and reused at the end of the life of the textile.

To continue to develop E-textiles and wearables more generally for health monitoring, further studies using a co-design method would be beneficial. In a co-design method, the participants are involved in the entire design process. Co-design allows the participants more input into the design process and allows for more iterations of the design. Moreover, the design can be altered for other types of applications.

This project has shown the importance of multidisciplinary collaboration. Participants for future co-design workshops should include technologists, designers and users. In addition, the knowledge of healthcare professionals (careers, occupations therapists, doctors) and specialists from other disciplines (social sciences) should be utilized, to answer further questions on the design, how the data should be used and shared, and how to ensure the uptake of monitoring devices.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

Ethical approval

Ethical approval (protocol code 2021/22-28) was granted by the Nottingham Trent University College of Art, Architecture, Design and Humanities (CAADH) Research Ethics Committee in December 2021. Informed consent was obtained from all participants.

Supplementary material

Supplemental online material can be found on Figshare at 10.6084/m9.figshare.22277233. Anonymised transcripts are available on request.

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