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'Smart – not only intelligent! ' Co-creating priorities and design direction for 'smart' footwear to support independent ageing.

With an ageing population there is a growing need for technology that enables older adults to live independently for longer. The EU Horizon2020 funded MATUROLIFE project is focused on developing solutions that embed smart textiles to support well-being and independence in older adults. The study described here aimed to explore and initiate development of 'smart' footwear embedding assistive technology. A qualitative research strategy was employed including interviews with 37 older adults and co-creation activities with 56 older adults. Participants were recruited from eight European countries (Belgium, France, Germany, Italy, Poland, Spain, Turkey, and United Kingdom). The results detail the specific needs that older adults have in relation to footwear based on the daily activities they take part in. Participants shared their footwear fashion preferences, as well as their priorities for assistive functionality. A set-of co-created priorities and concept ideas are presented that consider how footwear might enable independent ageing.

Keywords: assistive technology, well-being, fashion design, wearable electronics, co-design

1. Introduction

The use of assistive technology can help older adults live independently for longer and reduce care-needs. Assistive technology is an umbrella term covering the products, systems and services that maintain, or improve an individual's functioning and independence, thereby promoting their well-being (WHO, 2018). Despite the potential benefits, research suggests there are high abandonment rates of assistive technology and products are often regarded as unattractive and undesirable (Chaiwoo, 2013; Yusif, Soar, & Hafeez-Baig, 2016). To support technology development and adoption, consideration of the users and their relationships with the new technology is important (Park & DeLong, 2009). The EU-Horizon2020 (H2020-EU.2.1.3. Leadership in enabling and industrial technologies - Advanced materials) scheme funded the

MATUROLIFE project (http://maturolife.eu) to develop products that embed smart materials. The project team will build on processes to selectively metallise fibres within a textile, to produce a multi-functional material which maintains the properties of the textile (feel, drape, weight) whilst adding electronic connectivity. This will enable integration of electronics and the development of more discrete and functional assistive technology. Through a combination of active involvement of older adults in the development process and technological innovation, the project consortium will develop a range of assistive technology products including clothing, footwear, and furniture that meet the needs of the user. The focus of the research described here, relates specifically to the development of smart footwear solutions.

The fashion market has traditionally influenced the design of footwear and the prioritisation of style and footwear type, whilst potentially compromising the natural functioning of the foot (Menz, 2008; Coughlin & Thompson, 1995; McRitchie, Branthwaite, Chockalingam, & Research, 2018). Footwear design is particularly important for older adults to reduce the risk of falls, and help maintain mobility, quality of life and independence (Burns, Leese, & McMurdo, 2002; Muchna et al., 2018; Palomo-López et al., 2017). With age, there is an increased risk of conditions such as diabetes mellitus which can lead to poor foot health (Burns et al., 2002). Gait (i.e. the pattern of how a person walks) can also change, with an impact on balance and increased risk of falls (Goehring, Bringer, Broders, & Young, 2018; Menant, Steele, Menz, Munro, & Lord, 2008a).

Research has highlighted elements that should be considered when designing shoes for older adults. Footwear characteristics such as the toe box width, sole hardness and thickness can contribute to foot pain, deformity, reduced plantar tactile sensitivity and functional limitations (McRitchie, Branthwaite, & Chockalingam, 2018; Menant et al., 2008a; Menant et al., 2008b; Menz & Morris, 2005). Wearing high-heel shoes can increase the risk of falls (Goehring et al., 2018; Koepsell et al., 2004; Menant, Steele, Menz, Munro, & Lord, 2008b). Well secured footwear with enhanced insole properties and flexible soles may improve foot function and strengthen muscles. Shoes that fit well with secure fastenings have been suggested to minimise the risk of slips, trips and falls (McCann & Bryson, 2015; Menant et al., 2008b; Schwarzkopf, Perretta, Russell, & Sheskier, 2011).

During the first year of the MATUROLIFE project, qualitative research was undertaken to guide the early development of smart footwear for older adults. Here, smart footwear is anticipated to include sensors (e.g. to sense movement, heat, or vital signs) and electronic components (e.g. the battery, the aerial, etc.) that are interconnected through the use of selectively metallised fabrics. As a result, the footwear will provide assistive information to the wearers to support their independence. In line with research by Perry and colleagues, we argue that an approach driven by user needs is required to improve smart product development and future acceptance and commercialisation (Perry, Malinin, Sanders, Li, & Leigh, 2017). The research sought to explore the perspectives of older adults and understand their underlying needs and preferences in terms of style, colour, material, and cost. Furthermore, we explored how their independent living priorities could be translated into design solutions. Specifically, the research questions were:

1. What are the personal preferences of older adults and their experiences of footwear?

2. What are the underlying needs and concerns related to independent living that older adults would prioritise?

3. Which fashion and functionality priorities would older adults wish to embed in smart footwear?

4. Literature Review

Wearable electronics are body-worn garments with embedded electronic functionality (Berglin, 2013; Jones, 2015; Mattila, 2006; McCann & Bryson, 2015; Stoppa & Chiolerio, 2014; Weng, Chen, He, Sun, & Peng, 2016). Fabrics that can sense or respond to stimuli, and embed functionality such as the ability to conduct electricity, are often referred to as smart textiles or ‘e-textiles’ (Jones, 2015; Lee et al., 2015; Stoppa & Chiolerio, 2014; Stylios & Lam Po Tang, 2006). The extent of intelligence can include: (1) passive smart textiles (e.g. sensors that can only sense the environment); (2) active smart textiles that can sense and respond to stimuli in the environment (i.e. a sensor and an actuator function); and (3) very smart textiles that have the ability to adapt their behaviour to the circumstances (Tao, 2002; Van Langenhove & Hertleer, 2004). Increasingly the miniaturisation of circuits and micro-components make them almost invisible and easier to embed in flexible substrates (Jones, 2015; Zeng et al., 2014).

Wearable electronics applications include rechargeable fabrics (Lee et al., 2013); smart phone controls with built-in microphones, speakers and keypads to receive telephone calls (Chan, Estève, Fourniols, Escriba, & Campo, 2012); heating systems for apparel (i.e. outerwear, gloves and footwear) (Hu & Mondal, 2006b; Mondal, 2008; Rantanen et al., 2000); technical safety lighting using high-brightness LEDs; GPS tracking components; heart rate and respiration sensors for fitness and performance monitoring (Chan et al., 2012; Solaz et al., 2006; Van Langenhove & Hertleer, 2004); heating systems for sport performance enhancement (Hu & Mondal, 2006a, 2006b); and wearable therapy devices (Cherenack & van Pieterson, 2012; Jones, 2015; Langenhove, 2007). Assistive technology-based solutions may include garments with health monitoring capabilities or built-in communications and safety features. The monitoring of walking ability, and mobility, is increasingly exploited (Eskofier et al., 2017).

The literature on smart footwear relates primarily to fitness and healthcare (Ajami & Teimouri, 2015; Ariyatum, Holland, Harrison, & Kazi, 2005; Hegde, Bries, & Sazonov, 2016; Hwang, Chou, Fang, & Hwang, 2016; Jung, Oh, Lim, & Kong, 2013; Tan, Fuss, Weizman, & Troynikov, 2015). Eskofier et al. (2017) argue that smart shoes could provide accurate and flexible biomechanical analysis to monitor gait and enable non-obtrusive and non-stigmatizing integration of technology e.g. in the insole of a shoe (Eskofier et al., 2017). Gait assessment is useful as an indication of mobility, autonomy, health and quality of life (Muro-de-la-Herran, Garcia-Zapirain, & Mendez-Zorrilla, 2014; Rahemi, Nguyen, Lee, & Najafi, 2018). Smart insoles have been explored as mobile systems for gait analysis and for application to rehabilitation and exercise training (Lin, Wang, Zhuang, Tomita, & Xu, 2016; Tan, Fuss, Weizman, Woudstra, & Troynikov, 2015; Xu et al., 2012). Smart socks with embedded knitted pressure sensors have also been developed for gait analysis in rehabilitation and sport-related applications (Oks, Katashev, Zadinans, Rancans, & Litvak, 2016; Rosenberg et al., 2016; Eskofier et al., 2017).

Other potential functions of smart shoes include tracking, step and calorie counting, and the provision of biomedical information such as foot oxygen concentration (De Santis et al., 2014; Hwang et al., 2016). There has been particular focus on developments related to diabetes demonstrated through smart shoes (Najafi, Mohseni, et al., 2017), smart insoles (Najafi, Ron, et al., 2017) and smart socks (Elsayed & Elsaman, 2017; Najafi, Mohseni, et al., 2017; Perrier et al., 2014). Research has also considered navigation and falls. Sim et al. (2011) describe a prototype shoe that includes an accelerometer to detect falls. Other research has combined smart shoes with a cane to detect nearby obstacles. When an obstacle is detected, a message is sent to the user via the connected cane (Thakur, Sharma, Dhall, Rastogi, & Agarwal, 2016). The use of ultrasonic and infrared sensors, as part of an obstacle detection system integrated in a smart shoe for older adults and to support visual impairment, has also been investigated (Chandekar, Chouhan, Gaikwad, & Gosavi, 2017).

Whilst there is growing work in the area of smart shoes and in assistive technology, there is limited research that embeds the needs, requirements and expectations of older adults into the development of solutions as intended in the study described here. It is argued that the involvement of users is critical to developing solutions that are wearable and acceptable, rather than being driven predominantly by technological capability.

5. Methods

A qualitative research approach was adopted (Ritchie, Lewis, Nicholls, & Ormston, 2014). The data collection involved semi-structured interviews and co-creation activities (Ramaswamy & Ozcan, 2018; Sanders & Stappers, 2008). The research involved 93 older adults aged between 60 and 95 years (n=57 females and n=36 men) recruited through our partner network from eight of the European countries involved in the MATUROLIFE project (France, Italy, Poland, Spain, Turkey, Belgium, Germany and United Kingdom). The research was approved through the XXX University Ethical Approval process and additional approval was provided as required by each partner organisation.

There were three phases of data collection 1) Semi-structured interviews; 2) Exploratory co-creation workshops; 3) Footwear development co-creation workshops. These are summarised in Table 1 below.

Table 1: Overview of the methods employed for the data collection, and the participants involved in each.

[INCLUDE TABLE 1]

3.1: Semi-structured interviews

Semi-structured interviews were undertaken with 37 older adults, face to face in 6 countries. All participants lived in their own homes and were able to provide informed consent to take part in the research. The interview schedule explored threats to independence, everyday life experiences, where support was needed now and anticipated in the future, as well as current use of products and technology. Journey mapping (Martin, 2012) was used as a tool during the interview to explore and map out clothing and footwear preferences in respect to the activities performed during a typical day. The participants were asked to describe the activities they took part in during a typical day and then link these activities to the clothing and footwear they would wear or choose. The average length of the interviews was one hour. The interviews were recorded and transcribed in English for analysis.

3.2: Exploratory co-creation workshops

In total 37 older adults took part in the first 4 exploratory co-creation workshops (between 8 and 11 per workshop – as shown in Table 1). A co-creation approach involves designers and people not trained in design work working together in the development process (Sanders & Stappers, 2008). The exploratory workshops sought to further specify the needs of older adults and explore collaboratively how health and independence priorities could be addressed through design. At this stage the design direction was open and considered how independence might be supported through the design of a range of products including clothing, footwear and furniture.

During the workshops, participants were asked to work in collaboration with multi-disciplinary teams (including designers, manufacturers, psychologists, etc.) to first prioritise the needs and design priorities identified through the interviews, and then generate new ideas. This allowed the personal experience of the participants and the expertise of the multi-disciplinary team to be incorporated into the design process.

The workshops were conducted in the local language and the outputs translated into English. The workshops were scheduled over four hours with breaks. The activities included:

1. Exploring the concept of independence (activity 1A): a facilitated group discussion to define independence in older age. This was used to expand the interview findings around participant needs.
2. Co-creating solution spaces (activity 2A): a small group activity where participants were encouraged to develop futuristic ideas of how solutions in the home (in any form) could address the threats to independence identified through the semi-structured interviews and in activity 1a during the co-creation workshops.
3. Acceptability discussion (activity 3A): with the participants split into 2 groups they critiqued a range of clothing, footwear and furniture products to identify the characteristics, materials and styles they preferred and identify how they would improve the designs.

A range of tools were utilised, some of which included: flip charts, post-it notes and pre-prepared mood boards, and images during the co-creation activities, as illustrated in Figure 1 below.

[INCLUDE FIGURE 1]

Figure 1. Examples of the tools used and material generated during the exploratory workshops: a) Activity 1A: Exploring the concept of independence, using flipcharts and post-it notes. b) Activity 2A: Co-creating solution spaces. c) Activity 3A: Acceptability discussion.

3.3: Footwear development co-creation workshops

A further 2 co-creation workshops involving in total 19 participants (9 in the United Kingdom and 10 in Germany) focused specifically on the development of smart footwear. These workshops aimed to explore how the priorities identified in the exploratory workshops could be addressed through smart footwear. The workshops were scheduled for three hours including breaks. The co-creation activities included two main activities:

1. Independence priorities (activity 1B): the participants were asked to prioritise the health and independence related issues identified in the four exploratory workshops (as detailed in subsection 3.2) to indicate those that they most wanted to address during the workshop. They were given the issues on 11 individual strips of paper. Individually they were asked to select their top five priorities and discard the other five. Then, working in pairs, they agreed on their top four. The pairs then reported back to the group and the results were combined to agree the top 4 priorities.
2. Identifying style preferences (activity 2B): in the next activity participants were asked to sift through a collection of footwear images selected by project partners in different countries as well as footwear samples and designs produced by a partner shoe manufacturer and identify/tick which they would choose to wear, for which activities and why.
3. Concept development (activity 3B): in this activity 2 teams were formed with older adults working alongside project partners including an engineer, human

factors specialist, designers, and a footwear manufacturer. The teams were asked to propose smart footwear ideas that addressed the priorities identified in activity 1B, and embedded the style preferences from activity 2B. The facilitators encouraged consideration of the function of the smart footwear and how it might embed smart technology and materials. The project partners contributed technology knowledge and ideas around specific construction techniques and materials. The older adults were encouraged to share style preferences and ideas for how information might be presented back to them from the smart solutions. Sketches and ideas of the co-created smart footwear were gathered in A3 canvasses.

In Figure 2 below the tools/stimuli used to elicit the activities during the footwear development co-creation workshops are shown.

[INCLUDE FIGURE 2]

Figure 2. Tools/Stimuli the participants were asked to engage with: d) Activity 1B: Independence priorities. e) Activity 2B: Identifying style preferences that participants selected as preferred to embed smart technology. f) Activity 3B: Concept development, with older adults working alongside designers and experts.

6. Data analysis

A multi-method analysis approach was followed including Qualitative Content Analysis (QCA) and Thematic Analysis (TA) methods supported by NVivo (v.11 Pro for Windows, ©QSR International) (Bazeley & Jackson, 2013). The QCA method is particularly suited for studies that aim to ‘systematically describe the meaning of qualitative material by classifying parts of the material as instances of the categories of a coding frame’[1](Schreier, 2012, p. 8). The method was used to generate a Product Design Specification (PDS) and identify Experience Highlights (EH). TA is a method for identifying, analysing, organising, describing, and reporting themes found within a data set (Boyatzis, 1998; Braun & Clarke, 2006). Here, the method was used to explore and describe the major research themes (e.g. factors affecting independence; technology to promote independence and well-being of older adults, etc.) and explain the relationships between these themes. The codebook followed a hybrid strategy (i.e. it was informed deductively by the research objective and the literature review, and inductively by the data gathered). It was created in NVivo and validated to support the data coding and analysis of both the interview and workshop content. The facilitated workshop sessions resulted in recordings and written annotations on a number of canvasses, flip charts and visual images (e.g. sketches) which logged the discussion and design decisions that had been made. The text-based data was entered into the analysis process and the visual images used to evidence and illustrate the emergent themes.

7. Results

5.1: *‘You’d better look after your feet, then your feet will look after you’*

The interviews and exploratory workshops provided a broad view of participant preferences and experiences in relation to their everyday shoes. ‘Proper’ shoes were regarded as important for healthy ageing, and comfort was prioritised. It was recognised

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[1] A coding frame is the guiding conceptual scheme to record the codes and criteria used to classify the raw data (e.g. observations, interviews, videos, pictures, etc.) into nodes/categories. Coding frame is the term used when the QCA method is applied, whilst in Thematic Analysis it is referred to as ‘Codebook’.

that as the legs and feet bear the weight of the body one 'should look after your feet, and then your feet will look after you' [UK, Interview]. Participants explained that with increasing age, their footwear style and size preferences altered due to changes in their body and foot shape, as well their health.

> 'I wear shoes with flat heels, because I'm thicker. I used to love high heel shoes, but now I cannot wear them anymore. And that's what I miss. But I will not do anything about it because I have problems with my legs and walking.' [PL, Interview]

> 'I like the breathable shoes (i.e. XXX) that keep the feet dry, not sweaty. I have always had issues with my feet – sweaty, and now with this brand I solved my problem, they are incredible for your health feet.' [ES, Interview]

One participant who made use of a wheelchair and mobility scooter, indicated that durable footwear with strong soles were important when using mobility aids, especially for those who may drag their feet.

A common experience was an increase in shoe size (often by 1-2 sizes) with age. In some cases this was due to swelling, bunions, and crossed toes due to rheumatism. Preferences were indicated for open sandals in the summer, and flat, soft leather shoes in the winter. Waterproof textiles were noted as important, particularly in the UK. Comfort was consistently prioritised over fashion:

> 'I wear the same type/model in every weather condition, they might be pretty, or less pretty, the important thing is that they are comfortable. Priority is comfort, not the look.' [BE, Workshop #3]

> 'I have cross toes for rheumatism, hence in summer I can only wear open sandals; in winter it is an issue, I usually wear one size bigger.' [IT, Workshop #2]

> 'I had a bunion/hallux valgus, then I got operated, and now I need to have shoes that are comfy and soft, and hence when I find the right shoes I wear them all the time until they are completely worn. For me it is critical to have shoes 1 size bigger than you need – bigger shoes are more comfortable.' [TK, Interview]

The journey mapping activity indicated footwear preferences in the context of daily tasks and habits. For indoor activities, slippers with a gripping sole were preferred, in some cases specific footwear was required.

> 'In the house, I wear indoors shoes, I have been using pumps since I was diagnosed that I am diabetic, before that I used to walk barefoot. When you have diabetes, the soles of your feet become less sensitive. You are advised to wear light shoes rather than tread on something and not realize you've done it.' [UK, Interview]

Participants tended to be most active in the morning, both in the house and outdoors. Balance was identified as a key threat to independence, and a potential issue when undertaking household chores. Participants reported avoiding activities that involved working at height (e.g. using top cupboards, changing lightbulbs, cleaning the windows, etc.). Joint issues were not uncommon and affected confidence to engage in activities.

For leisure activities and tasks undertaken away from the home (e.g. going to the bank, shopping etc.) comfortable casual and flat shoes were preferred. In terms of fastenings, preferences varied and included with and without laces, or Velcro. Velcro was preferred amongst those affected by arthritis.

> 'Since I fell and I have scarce mobility, I cannot bend, so I do not use laces, and need shoes easy to put on.' [FR, Interview]

In contrast others felt that Velcro was less secure and increased the fear of a trip or fall. For physical activity, male and female participants indicated wearing sport shoes. For formal and special occasions (e.g. going to the theatre, dining out) female participants wanted to be able to wear shoes with a small heel, like wedge or kitten heels.

> 'I talk about this with my girlfriends, and we all agree that little heel is good.' [ES, Workshop#1]

All participants prioritised a non-slippery sole that grips well to minimise the risk of slips and falls. Falls were a significant concern. Some participants had attended workshops or read information to help reduce their personal risk. They were aware of the risk presented by footwear choice and the surface under foot. One participant shared their experience of falling on the stairs three times resulting in broken bones and poor mobility. This had led to a medical recommendation of orthopaedic shoes, but there were concerns about both cost and quality.

> 'After I fell I bought a model for 230 euros, but at the end I do not use them. I bought because I am also diabetic, they are in leather, but the leather is not good in my feet, it hurts my feet.' [BE, Workshop#3]

In relation to acceptable budget, the typical price paid for shoes was around 65 euros or 60 British pounds, with participants indicating a preference for specific brands and shops. Overall, function and quality were important and participants would consider paying more for good quality and functionally beneficial shoes. Waterproofing, ankle protection, additional stability and support to address pronation, were elements that they may be willing to pay more for.

> 'I take advice for the running shoes to checking running gait. They say I'm an over pronator, so when you are running your knees go in. It's necessary to wear shoes with higher in-step, the supported step can help you run.' [UK, Interview]

One participant noted that their preferred brand whilst more expensive offers specialised shoes for the older market; the comfort and quality justify the higher cost.

> 'If you choose XXX you spend 150 euros, but they are really soft. For example, I used to wear boots, but in the last years they were really uncomfortable in my feet.

I was suggested to try XXX, and I could feel the difference. I can have again the boots now, they are really comfortable. Their leather is really soft, and they have wider models, because they are designed for the older people.' [IT, Workshop#2]

The analysis of the interviews enabled an extensive set of footwear related requirements and preferences, as well as identification of participant experience expectations related to footwear. Some examples of these are provided in Table 2 below. It was noted that products should be easy to clean, durable, and natural, not plastic or synthetic to reduce irritation. There was a preference for footwear that was colourful, attractive, practical, light weight, comfortable to wear, and easy to get on and off. A range of 'looks' to meet individual tastes were important, as was subtlety and not being specifically styled or marketed for older adults. Ideally footwear would be available in mixed sizes (e.g. a size 6 and 7 in a pair) as a size difference between feet was often reported.

Table 2. Example design requirements and experience highlights for smart footwear.

[INCLUDE TABLE 2]

5.*2* 'My feet are swollen, so th*e shoes have to relieve my feet'*

The interviews and the four exploratory workshops identified threats to independence that participants would like to see addressed through smart products. Those regarded as most significant by the participants are listed in Table 3 below. The importance of good health to enable one to move around independently was important to all.

Table 3. The identified threats to independence.

[INCLUDE TABLE 3]

5.3: ***'Smart – not only intelligent!'***

During the two footwear focused co-creation workshops, the eleven threats outlined in Table 3 were prioritised by the older adult participants. They were prioritised slightly differently in the UK and German workshops as presented in Table 4 below.

Table 4. The prioritised threats to independence in the UK and German workshops - Independence priorities (activity 1B).

[INCLUDE TABLE 4]

There could be a number of reasons for this, including the differing weather and environmental conditions the participants are exposed to, or their underlying health. There was a level of agreement with 3 out of the 4 selected priorities. Participants then explored how those threats might be addressed through footwear. They felt that smart assistive footwear could potentially offer a range of health monitoring functions for example, monitoring and alerting them to issues with heart rate, blood pressure or circulation. 'Talking shoes' could provide acoustic alerts to the wearer (e.g. 'slow down', 'watch out for a hazard', 'stop for rest', 'get up and walk around') and alert others to a need for help. To address concerns around stability and risk of falling, the participants suggested sensors that would guide balance and indicate reducing stability. Guidance and tracking systems were also of interest particularly to provide reassurance for the family. Garments to support temperature control were considered with a particular focus on the extremities e.g. socks. They considered garments that could respond to body temperature, providing both heating and cooling functions. To tackle swelling feet and poor circulation, it was suggested that footwear could offer massage and reflexology, as well as adapting to changes in the size and shape of the foot for improved comfort.

Figure 3 illustrates some of the ideas generated through discussion during the concept development activity.

[INCLUDE FIGURE 3]

Figure 3. Example of outputs from the Footwear development co-creation workshops, and specifically from activity 3B (concept development): g) Output of a sketch, regarding the heel height and shape. h) Output of a canvass, where ideas and sketches around the proposed smart footwear were brought together.

Table 5 provides an example of the ideas generated in consideration of 'I feel unsteady on my feet and fear falling'. The participants considered how this problem might be addressed through technology, as well as elements of style that might be used to support balance and stability.

Table 5. Example of output from the Footwear development co-creation workshops of ideas generated to address 'I feel unsteady on my feet and fear falling'.

[INCLUDE TABLE 5]

The design decisions made by the older adults echoed findings in the interviews and earlier workshops indicating a preference for a classic aesthetic, comfortable fit and ease of removal, without laces and appropriately styled Velcro. Participants considered breathability for summer, and waterproofing and warmth for winter. They considered the materials that might be selected to cater for changes in shape and size and swelling. In sketching out alternatives they ensured the shoe upper was not too low at the toe, that they had a back, and were comfortable and easy to put on. Some female participants considered inclusion of a kitten heel for a feeling of elegance and in reminiscence of their youth. Central to the design exploration was that any 'assistance' offered by the shoe would be subtle and discrete and would not stigmatise the wearer. The heel was considered as a space for embedding technology, with caution to ensure it was not too high. Smart insoles that could be moved between different shoes were considered.

8. Discussion and conclusion

This paper has presented the findings of a series of user engagement activities undertaken to guide the development of smart footwear to enhance well-being and independence in older adults. The findings have provided useful insight into the views, preferences and requirements of older adults. The co-creation setting has enabled discussion of their priorities for assistive technology, their concerns about their health and independence, and enabled exploration of fashion and functionality. Key priorities for assistive smart footwear have included solutions to inform the user about the risk of falling and change in balance; relieve or adapt to swelling of the feet; address aches and pains; help maintain temperature; and provide support with navigation.

As well as taking a co-creation approach, the research has sought to understand human activity and the context of shoe use. As such, the findings have provided information about the choice of footwear for indoor and outdoor activities. Whilst the countries we have undertaken the research in have different weather conditions and trends, there were common views on both purchasing preferences and in terms of future health needs. The concerns of people as they age and their fear of loss of independence were similar. It did not prove difficult to reach prioritised areas in which assistive technology is needed.

There is opportunity for further development of smart shoes and consideration of how they may provide assistance in day to day living. Bringing together the needs, requirements and expectations of older adults into the development of combined solutions is important. There is a move to consider and involve older adults in fashion recognising the spending power and desire of this growing population (e.g. Sadkowska, et al., 2015). Projects have looked to involve both older men and women and co-create solutions that address their needs. It is argued here that in a technically complex application such as smart footwear, the involvement of users, whilst challenging is critical to developing solutions that are wearable and acceptable.

The MATUROLIFE project is focused on integrating smart materials to provide discrete assistive technology. The technology is in development through a chemical and material science process that may be challenging for our participants to imagine. Through the workshops we sought to inform participants of the potential of the technology. We provided some educational media on shoe manufacturing (including shoe making and assembly, and shoe fabrics and properties), the possibility of the metallised textiles, as well as introducing design and co-creation methods. This was an important part of the workshop agenda to ensure that all participants felt that they could participate and understand the process. Some older adults may be reluctant to embrace assistive technology or indeed smart technology. This was not felt to be the case with those participants that joined the research activities described. However, ongoing research will need to ensure though that MATUROLIFE products are designed also for the least willing, and that barriers to use and adoption and any stigma are minimised through design.

Following the workshops, the design partners who attended and participated in the workshop further developed the ideas generated. They refined the designs embedding the style preferences discussed and exploring further the technology that might be embedded to enable the proposed assistive functions. An example is shown below in Figure 4.

[INCLUDE FIGURE 4]

Figure 4. Further development of footwear concepts by the design team.

The range of ideas was further developed and reviewed by the wider MATUROLIFE project team to consider which were feasible for development. This was achieved through a team meeting including 20 of the project team (with representation from most partners). The designs were reviewed against a set of criteria including the extent to which the design incorporated a metallised textile, mapped to identify user needs, technical feasibility, manufacturing difficulty and commercial viability.

Ongoing development is now focused on the footwear concept directed at balance and falls prevention. Careful consideration of how metallised textiles can be best utilised within the design to ensure wearability of the shoe as smart functionality is added will be achieved by iterative testing. A stakeholder panel has been formed as well as user testing groups to ensure ongoing involvement of the representative user groups throughout the three-year project. It is intended that by working in multi-disciplinary teams in conjunction with the direct users, acceptable and desirable products can be developed despite the technical complexity and traditional stigma associated with assistive technology.

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Disclosure statement

No conflict of interest is reported by the authors.

References

Ajami, S., & Teimouri, F. (2015). Features and application of wearable biosensors in medical care. Journal of research in medical sciences: the official journal of

Isfahan University of Medical Sciences, 20(12), 1208-1215. doi:10.4103/1735-1995.172991

Ariyatum, B., Holland, R., Harrison, D., & Kazi, T. (2005). The future design direction of Smart Clothing development. The Journal of the Textile Institute, 96(4), 199-210. doi:10.1533/joti.2004.0071

Armstrong, D. G., Najafi, B., & Shahinpoor, M. (2017). Potential applications of smart multifunctional wearable materials to gerontology. Gerontology, 63(3), 287-298. doi:10.1159/000455011

Bazeley, P., & Jackson, K. (2013). Qualitative Data Analysis with NVivo. London: SAGE Publications Ltd.

Berglin, L. (2013). Smart textiles and wearable technology. Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:hb:diva-4616

Boyatzis, R. E. (1998). Transforming qualitative information: Thematic Analysis and Code Development. Thousand Oaks, CA: SAGE Publications.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative Research in Psychology, 3(2), 77-101. doi:10.1191/1478088706qp063oa

Burns, S. L., Leese, G. P., & McMurdo, M. E. T. (2002). Older people and ill fitting shoes. Postgraduate Medical Journal, 78(920), 344.

Chaiwoo, L. (2013). Adoption of smart technology among older adults: Challenges and Issues. Public Policy & Aging Report, 24(1), 14–17.

Chan, M., Estève, D., Fourniols, J.-Y., Escriba, C., & Campo, E. (2012). Smart wearable systems: Current status and future challenges. Artificial Intelligence in Medicine, 56(3), 137-156. doi:https://doi.org/10.1016/j.artmed.2012.09.003

Chandekar, T., Chouhan, R., Gaikwad, R., & Gosavi, H. (2017). Obstacle detection and navigation system for visually impaired using smart shoes. International Research Journal of Engineering and Technology (IRJET), 4(2), 574-577.

Cherenack, K., & van Pieterson, L. (2012). Smart textiles: Challenges and opportunities. Journal of Applied Physics, 112(9), 091301. doi:10.1063/1.4742728

Coughlin, M. J., & Thompson, F. M. (1995). The high price of high-fashion footwear. Instr Course Lect, 44, 371-377.

De Santis, A., Gambi, E., Montanini, L., Raffaeli, L., Spinsante, S., & Rascioni, G. (2014, 10-12 Sept. 2014). A simple object for elderly vitality monitoring: The smart insole. Paper presented at the 2014 IEEE/ASME 10th International Conference on Mechatronic and Embedded Systems and Applications (MESA).

Delgado-Gonzalo, R., Hubbard, J., Renevey, P., Lemkaddem, A., Vellinga, Q., Ashby, D., . . . Bertschi, M. (2017, 11-15 July 2017). Real-time gait analysis with accelerometer-based smart shoes. Paper presented at the 2017 39th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC).

Elsayed, E. M., & Elsaman, S. I. L. (2017). Synthesis of smart medical socks for diabetic foot ulcers patients. Fibers and Polymers, 18(4), 811-815. doi:10.1007/s12221-017-1256-9

Eskofier, M. B., Lee, I. S., Baron, M., Simon, A., Martindale, F. C., Gaßner, H., & Klucken, J. (2017). An overview of smart shoes in the internet of health things: gait and mobility assessment in health promotion and disease monitoring. Applied Sciences, 7(10). doi:10.3390/app7100986

Goehring, M., Bringer, N., Broders, J., & Young, E. (2018). The effects of footwear on postural sway: a pilot study. Physical & Occupational Therapy In Geriatrics, 1-12. doi:10.1080/02703181.2018.1476432

Hatton, A. L., Rome, K., Dixon, J., Martin, D. J., & McKeon, P. O. (2013). Footwear interventions. Journal of the American Podiatric Medical Association, 103(6), 516-533. doi:10.7547/1030516

Hegde, N., Bries, M., & Sazonov, E. (2016). A comparative review of footwear-based wearable systems. Electronics, 5(48), 1-28. doi:10.3390/electronics5030048

Hu, J., & Mondal, S. (2006a). Study of shape memory polymer films for breathable textiles. In H. R. Mattila (Ed.), Intelligent textiles and clothing. Cambridge: CRC - Woodhead Publishing Limited.

Hu, J., & Mondal, S. (2006b). Temperature sensitive shape memory polymers for smart textile applications. In H. R. Mattila (Ed.), Intelligent textiles and clothing. Cambridge: CRC - Woodhead Publishing Limited.

Hwang, P.-Y., Chou, C.-C., Fang, W.-C., & Hwang, C.-M. (2016, 27-29 May 2016). Smart shoes design with embedded monitoring electronics system for healthcare and fitness applications. Paper presented at the 2016 IEEE International Conference on Consumer Electronics-Taiwan (ICCE-TW).

Jeon, S., Lee, C., Han, Y., Seo, D., & Jung, I. (2017, 8-10 Jan. 2017). The smart shoes providing the gait information on IoT. Paper presented at the 2017 IEEE International Conference on Consumer Electronics (ICCE).

Jones, D. C. (2015). The role of wearable electronics in meeting the needs of the active ageing population. In J. McCann & D. Bryson (Eds.), Textile-led design for the active ageing population. Cambridge: Elsevier Woodhead Publishing.

Jung, P.-G., Oh, S., Lim, G., & Kong, K. (2013). A Mobile Motion Capture System Based on Inertial Sensors and Smart Shoes. Journal of Dynamic Systems, Measurement, and Control, 136(1), 011002-011002-011009. doi:10.1115/1.4025207

Koepsell, T. D., Wolf, M. E., Buchner, D. M., Kukull, W. A., LaCroix, A. Z., Tencer, A. F., . . . Larson, E. B. (2004). Footwear Style and Risk of Falls in Older Adults. Journal of the American Geriatrics Society, 52(9), 1495-1501. doi:doi:10.1111/j.1532-5415.2004.52412.x

Langenhove, L. v. (Ed.) (2007). Smart textiles for medicine and healthcare : materials, systems and applications. Boca Raton, FL: Cambridge : Woodhead, Boca Raton, FL : CRC Press.

Lee, J., Kwon, H., Seo, J., Shin, S., Koo, J. H., Pang, C., . . . Lee, T. (2015). Conductive fiber-based ultrasensitive textile pressure sensor for wearable electronics. Advanced Materials, 27(15), 2433-2439. doi:10.1002/adma.201500009

Lee, Y. H., Kim, J.-S., Noh, J., Lee, I., Kim, H. J., Choi, S., . . . Choi, J. W. (2013). Wearable textile battery rechargeable by solar energy. Nano Letters, 13(11), 5753-5761. doi:10.1021/nl403860k

Lin, F., Wang, A., Zhuang, Y., Tomita, M. R., & Xu, W. (2016). Smart Insole: A wearable sensor device for unobtrusive gait monitoring in daily life. IEEE Transactions on Industrial Informatics, 12(6), 2281-2291. doi:10.1109/TII.2016.2585643

Lord, S. R. (2016). Virtual reality and the prevention of falls in the real world. The Lancet, 388(10050), 1132-1134. doi:https://doi.org/10.1016/S0140-6736(16)31347-2

Martin, B. (2012). Universal methods of design: 100 ways to research complex problems, develop innovative ideas, and design effective solutions (Digital ed.. ed.). Beverly, MA: Rockport Publishers.

Mattila, H. R. (Ed.) (2006). Intelligent textiles and clothing. Cambridge: CRC - Woodhead Publishing Limited.

McCann, J., & Bryson, D. (Eds.). (2015). Textile-led design for the active ageing population. Cambridge: Elsevier Woodhead Publishing.

McRitchie, M., Branthwaite, H., Chockalingam, N. J. J. o. F., & Research, A. (2018). Footwear choices for painful feet – an observational study exploring footwear and foot problems in women. Journal of Foot and Ankle Research, 11(1), 23. doi:10.1186/s13047-018-0265-2

Menant, J. C., Steele, J. R., Menz, H. B., Munro, B. J., & Lord, S. R. (2008a). Effects of footwear features on balance and stepping in older people. Gerontology, 54(1), 18-23. doi:10.1159/000115850

Menant, J. C., Steele, J. R., Menz, H. B., Munro, B. J., & Lord, S. R. (2008b). Optimizing footwear for older people at risk of falls. Journal of Rehabilitation Research and Development, 45(8), 1167-1181.

Menz, H. B. (2008). Foot problems in older people: Assessment and Management. Philadelphia: Churchill Livingstone Elsevier.

Mickle, K. J., Munro, B. J., Lord, S. R., Menz, H. B., & Steele, J. R. (2010). Foot pain, plantar pressures, and falls in older people: A Prospective Study. Journal of the American Geriatrics Society, 58(10), 1936-1940. doi:doi:10.1111/j.1532-5415.2010.03061.x

Mondal, S. (2008). Phase change materials for smart textiles – An overview. Applied Thermal Engineering, 28(11), 1536-1550. doi:https://doi.org/10.1016/j.applthermaleng.2007.08.009

Muchna, A., Najafi, B., Wendel, C. S., Schwenk, M., Armstrong, D. G., & Mohler, J. (2018). Foot problems in older adults. journal of the american podiatric. Medical Association, 108(2), 126-139. doi:10.7547/15-186

Muro-de-la-Herran, A., Garcia-Zapirain, B., & Mendez-Zorrilla, A. (2014). Gait analysis methods: an overview of wearable and non-wearable systems, highlighting clinical applications. Sensors, 14(2), 3362-3394. doi:10.3390/s140203362

Najafi, B., Mohseni, H., Grewal, G. S., Talal, T. K., Menzies, R. A., & Armstrong, D. G. (2017). An optical-fiber-based smart textile (smart socks) to manage biomechanical risk factors associated with diabetic foot amputation. Journal of

Diabetes Science and Technology, 11(4), 668-677. doi:10.1177/1932296817709022

Najafi, B., Ron, E., Enriquez, A., Marin, I., Razjouyan, J., & Armstrong, D. G. (2017). Smarter sole survival: Will neuropathic patients at high risk for ulceration use a smart insole-based foot protection system? Journal of Diabetes Science and Technology, 11(4), 702-713. doi:10.1177/1932296816689105

Oks, A., Katashev, A., Zadinans, M., Rancans, M., & Litvak, J. (2016, 2016//). Development of smart sock system for gate analysis and foot pressure control. Paper presented at the XIV Mediterranean Conference on Medical and Biological Engineering and Computing 2016, Cham.

Palomo-López, P., Becerro-de-Bengoa-Vallejo, R., Losa-Iglesias, M. E., Rodríguez-Sanz, D., Calvo-Lobo, C., & López-López, D. (2017). Footwear used by older people and a history of hyperkeratotic lesions on the foot: A prospective observational study. Medicine, 96(15), e6623-e6623. doi:10.1097/MD.0000000000006623

Park, J., & DeLong, M. (2009). Understanding new technology adoption in the apparel and footwear industry within a social framework: a case of rapid prototyping technology. International Journal of Fashion Design, Technology and Education, 2(2-3), 101-112. doi:10.1080/17543260903349007

Perrier, A., Vuillerme, N., Luboz, V., Bucki, M., Cannard, F., Diot, B., . . . Payan, Y. (2014). Smart diabetic socks: embedded device for diabetic foot prevention. IRBM, 35(2), 72-76. doi:https://doi.org/10.1016/j.irbm.2014.02.004

Perry, A., Malinin, L., Sanders, E., Li, Y., & Leigh, K. (2017). Explore consumer needs and design purposes of smart clothing from designers' perspectives. International Journal of Fashion Design, Technology and Education, 10(3), 372-380. doi:10.1080/17543266.2016.1278465

Rahemi, H., Nguyen, H., Lee, H., & Najafi, B. (2018). Toward smart footwear to track frailty phenotypes: using propulsion performance to determine frailty. Sensors, 18(6). doi:10.3390/s18061763

Rajagopalan, R., Litvan, I., & Jung, T.-P. (2017). Fall prediction and prevention systems: recent trends, challenges, and future research directions. Sensors, 17(11), 2509.

Ramaswamy, V., & Ozcan, K. (2018). What is co-creation? An interactional creation framework and its implications for value creation. Journal of Business Research, 84, 196-205. doi:10.1016/j.jbusres.2017.11.027

Rantanen, J., Alfthan, N., Impio, J., Karinsalo, T., Malmivaara, M., Matala, R., . . . Vanhala, J. (2000, 16-17 Oct. 2000). Smart clothing for the arctic environment. Paper presented at the Digest of Papers. Fourth International Symposium on Wearable Computers.

Ritchie, J., Lewis, J., Nicholls, M. C., & Ormston, R. (Eds.). (2014). Qualitative Research Practice: A Guide for Social Science Students and Researchers. London: SAGE Publications.

Rosenberg, S., Rosario, E., Yeung, J., Catolico, D., Daniel, R., Lovell, R., . . . Tang, R. (2016). Evaluation of a wearable & smart socks & gait monitoring system for improving rehabilitation. Archives of Physical Medicine and Rehabilitation, 97(10), e77. doi:10.1016/j.apmr.2016.08.234

Sadkowska, A., Wilde, D., & Fisher, T. (2015). Third age men's experience of fashion and clothing: an interpretative phenomenological analysis. Age Culture Humanities: An Interdisciplinary Journal(2), 35-70.

Sanders, E. B. N., & Stappers, P. J. (2008). Co-creation and the new landscapes of design. CoDesign, 4(1), 5-18. doi:10.1080/15710880701875068

Schreier, M. (2012). Qualitative Content Analysis in Practice. London: SAGE Publications.

Schwarzkopf, R., Perretta, D. J., Russell, T. A., & Sheskier, S. C. (2011). Foot and shoe size mismatch in three different New York City populations. J Foot Ankle Surg, 50(4), 391-394. doi:10.1053/j.jfas.2011.04.030

Sim, S. Y., Jeon, H. S., Chung, G. S., Kim, S. K., Kwon, S. J., Lee, H., & Park, K. S. (2011, 30 Aug.-3 Sept. 2011). Fall detection algorithm for the elderly using acceleration sensors on the shoes. Paper presented at the 2011 Annual International Conference of the IEEE Engineering in Medicine and Biology Society.

Solaz, J., Belda-Lois, J. M., Garcia, A. C., Barbera, R., Dora, T. V., Gomez, J. A., . . . Prat, J. M. (2006). Intelligent textiles for medical and monitoring applications. In H. R. Mattila (Ed.), Intelligent textiles and clothing. Cambridge: CRC - Woodhead Publishing Limited.

Stoppa, M., & Chiolerio, A. (2014). Wearable Electronics and Smart Textiles: A Critical Review. Sensors, 14(7), 11957.

Stylios, G. K., & Lam Po Tang, S. (2006). An overview of smart technologies for clothing design and engineering. International Journal of Clothing Science and Technology, 18(2), 108-128. doi:10.1108/09556220610645766

Tan, A. M., Fuss, F. K., Weizman, Y., & Troynikov, O. (2015). Development of a smart insole for medical and sports purposes. Procedia Engineering, 112, 152-156. doi:https://doi.org/10.1016/j.proeng.2015.07.191

Tan, A. M., Fuss, F. K., Weizman, Y., Woudstra, Y., & Troynikov, O. (2015). Design of low cost smart insole for real time measurement of plantar pressure. Procedia Technology, 20, 117-122. doi:https://doi.org/10.1016/j.protcy.2015.07.020

Tao, X.-M. (2002). Sensor in garments. Textile Asia, 38-41.

Thakur, S., Sharma, P., Dhall, P., Rastogi, S., & Agarwal, R. (2016). Smart Assistive Shoes for the blind people. International Journal on Recent and Innovation Trends in Computing and Communication, 4(9), 47-49.

Van Langenhove, L., & Hertleer, C. (2004). Smart clothing: a new life. International Journal of Clothing Science and Technology, 16(1/2), 63-72. doi:10.1108/09556220410520360

Virginia, P. (2013). Smart Materials for Healthcare. Retrieved from http://www.meldrenachapin.com/blog/wordpress/2013/02/15/smart-materials-for-healthcare/

Weng, W., Chen, P., He, S., Sun, X., & Peng, H. (2016). Smart Electronic Textiles. Angewandte Chemie International Edition, 55(21), 6140-6169. doi:10.1002/anie.201507333

WHO. (2018, 18 May). Assistive technology. Retrieved from http://www.who.int/news-room/fact-sheets/detail/assistive-technology

Xu, W., Huang, M.-C., Amini, N., Liu, J. J., He, L., & Sarrafzadeh, M. (2012). Smart insole: a wearable system for gait analysis. Paper presented at the Proceedings of the 5th International Conference on PErvasive Technologies Related to Assistive Environments, Heraklion, Crete, Greece.

Yusif, S., Soar, J., & Hafeez-Baig, A. (2016). Older people, assistive technologies, and the barriers to adoption: A systematic review. International Journal of Medical Informatics, 94, 112-116. doi:https://doi.org/10.1016/j.ijmedinf.2016.07.004

Zeng, W., Shu, L., Li, Q., Chen, S., Wang, F., & Tao, X.-M. (2014). Fiber-Based Wearable Electronics: A review of materials, fabrication, devices, and applications. Adv Mater, 26(31), 5310-5336. doi:doi:10.1002/adma.201400633