Consumer Acceptance of Smart Textiles: A Human-Centred Approach to the Design of Temperature-Sensing Socks

Introduction

'Breaking the rules' of fashion may require new thinking and practices that contribute to a healthier, better, and more prosperous world for everyone. In part this can be realised by drawing on knowledge from different disciplines and the building of new collaborative partnerships. One promising partnership lies in the rapid advances in information and nano-technologies and the opportunities they provide to transform clothing and concepts of fashion.

This paper examines the application of information technology and material science to smart textiles and how they may lead to healthier lives for a large and growing population. Diabetes is a significant health threat, with the number of people diagnosed in the UK doubling since 1996 (Diabetes UK 2015) The disease has debilitating and life-threatening consequences and diabetics are prone to develop foot ulcers, which may lead to complications, including amputation. Temperature changes in the feet are a good predictor of ulceration, and patients and their clinicians will benefit from an early warning system that can detect changes. This paper explores the user experience, comfort level and the physical properties of temperature-sensing socks (TSS) that use temperature sensing yarns.

To measure the physical characteristics of the socks two different methods were used in a participatory approach with the stakeholders. These were a wear trial with potential end-users and second, a focus group to discuss the wear trial results with stakeholders, who included the developers of the socks, designers, fashion marketing researchers and participants of the wear trial. Each method was chosen as a way to engage with different stakeholders to enable them to discuss their experiences, their knowledge into the research process and thereby gain new perspectives and insights to the project.

Literature review

Smart textiles are determined by electrical, thermal, mechanical, chemical, magnetic and other elements, that sense and communicate conditions and stimuli between the wearer and the environment (Tao 2001). E-textiles are a subset of this group, and consist of "clothing or technical textiles with electronic components integrated into them" (Kohler et al. 2011, p.497). The production of electrical and electronic textiles are primarily defined by insertion and integration techniques, inserting pre-packaged electronics into pockets, stitching components to surface of the textile, and integrating functionality into the textile using conductive threads, printing technology and integrating electronics into clothing accessories, such as belts (Cork et al. 2013).

The application of smart textiles to healthcare follows the adoption of best practices in health care innovation (Thakur et.al. 2012). Implementation of those practices ensures patient safety and optimises outcomes by helping health care professionals (HCP) to work smarter, faster, better and more cost-effectively. Connected health or technology embedded care (TEC) involves the convergence of healthcare technology, digital media and mobile devices. The successful development of smart textiles from research and development to market (Park & Jayaraman 2010) depends on understanding user's needs and how they can be met, reducing cost and improving the quality of service or performance, and enhanced convenience. Furthermore, the adoption of an innovative product is affected by its relative advantage, compatibility, complexity, observability and trialability (Rogers 2003). Therefore, the ability to observe how others are using the innovation and opportunities for trial can overcome the barriers and increase the chance of adoption (Park & Jayaraman, 2010).

An important innovative component of TSS (figure 1) is temperature-sensing yarn in which nano- sensors are glued in polyester copper yarn encased in a tubular knitted sleeve and then woven into the socks, a data processing box for wireless communications and a battery energy supply.

Data processing, Communication (wireless) and energy supply

Temperature sensing yarn woven in the socks

Figure 1: Temperature sensing socks

The sensors are integrated in the temperature-sensing yarn (TSY) and woven into the socks to acquire body temperature information from the individual and environment. The communication system in the yarn then transmits the data to an application in a smart phone for storage and analysis. This knowledge- based decision support system can help health care professionals to interpret the data, diagnose the individual's condition and develop an appropriate treatment administered in a timely manner. The treatment can be initiated by an individual, health care professional or triggered automatically by the monitoring site if the user is unable to respond to data or has previously authorised an automatic intervention (Park & Jayaraman, 2010).

However, there are various barriers to the development of TEC, including widespread concerns about quality, reliability, data overload, privacy and security. Another problem is that HCPs are often reluctant to engage with technology mainly due to the scale and pace of change, lack of education and training and concerns over liability and funding (Deloitte, 2015). Data privacy and how data is stored, shared, handled and accessed to the benefit of everyone has become an important issue (McKernan 2016). Concerns about cost effectiveness can be reduced by improving the quality and reliability of the devices and applications, and reducing the cost of digital technology (Deloitte 2015). For example, technologists' learning from the data, the modelling of data and simulations can make the technology more accessible and as a result make it more affordable and available for end users (Green 2016).

Methodology

The research question that arises is: what causes the participants to accept or reject temperature sensing socks? The study is conducted in a real world setting, where there is a need for the researcher to work with participants in a collaborative process aimed at improving and understanding their world in order to change the system. Participatory Action Research (PAR) was chosen for its cyclical process of exploration, knowledge construction and implementation

(McTaggart, 1997). PAR is a recursive process that involves a spiral of adaptable steps in four stages to:

- Question the issue of user acceptance of temperature sensing socks in two ways: socks with and without sensors during a wear trial
- Reflect on and investigate the wear trial results
- Develop an action plan combining qualitative and quantitative methods
- Review the physical characteristics and marketability of the socks with different stakeholders in a focus group

In order to test the physical properties of the TSS, a wear trial was undertaken with six participants and the results were discussed in a focus group of ten participants to examine the results and sales opportunity of the socks. The research was designed to test the user acceptability of the temperature sensing socks in terms of physical characteristics, rather than the diagnostic properties.

Product design

An understanding of the design of the TSS and the placement of sensors in the TSY was gained through the researcher's involvement in the development of the mock TSS. The purpose was to create fourteen pairs of socks for wear trial, half of which had sensors and the other half had none. The sensors were fixed to a polyester fiber and copper wire and encased within a yarn 'sleeve'.

The sensors constantly measure the temperature of the feet and if the temperature starts to reduce then this can be a possible indication of developing ulcers. The sensors were encased in TSY and the sensors were marked green to identify the sensor position in the socks (figure 2). However, the sensors were not activated in the mock TSS used for wear trial.

Figure 2: Temperature sensor yarn (TSY) with sensors marked in green

Temperature sensing socks with sensors

The socks were knitted on a computerised knitting machine using 10 gauge 50/50 polyester cotton yarn, and the top rib was combined with spandex or lycra for increased elasticity. The knitting process included creation of channels in the bottom of the socks into which the temperature sensing yarns were woven. In order to incorporate the temperature-sensing yarns into the socks, the sock was put onto a dummy foot; the sensor points on the dummy foot were then mapped onto the sock. The different orientations of the sensors for left and right feet were marked separately in each pair of socks

The TSY were woven into five channels knitted in the bottom of the socks and the sensors were exactly positioned in the marked area in seven pairs of dummy socks. The remaining seven pairs were woven with TSY that did not include sensors.

Attaching dummy data the processing box to the TSS

The temperature-sensing socks included a data processing box containing circuitry and batteries. This enabled communication between the sensors in the socks and a phone. Circuitry and electronics boxes were created for the dummy socks used in the trial to give them equivalent weight and feel to functional socks. In order to achieve this, the ends of the TSY were glued to strips of circuit board. The strips were hidden under a hand sewn pocket right below the top rib of the sock.

For the non-sensing socks, a small, plastic box of similar weight and size to that used in functional temperature-sensing socks was then added. To ensure that the weight of the boxes was equivalent to those used in functional temperature-sensing socks, the circuit components and batteries for energy supply were weighed and replaced with an equal weight of plasticine. This was then placed in the pocket at the top of the socks. Velcro was attached within the pocket opening to avoid the data processing box slipping out of the pocket. The final TSS used for wear trial is shown in figure 3.

Figure 3: Temperature sensing socks developed for wear trial

Methods for data collection

The data collection methods involved a series of practical investigations to measure the physical characteristics of the dummy socks with and without sensors. Research related to the adoption of innovations suggests a prominent role for perceived ease of use. Perceived ease of use is defined as the degree of which a person believes that using a particular system would be free of effort (Davis et.al. 1989). From this definition, we claim that the temperature sensing socks is perceived to be easy to use and comfortable, which is more likely to be accepted by users.

Usability is the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use (ISO 9241

DIS 1994). According to Sande (1999) iterative modelling and evaluation is a good tool for ensuring usability and likability. In the design process the decision makers need information on which their decisions can be based. The reasons for modelling and prototyping fall into three broad classes: idea generation, communication and testing (Sande 1999). Of the three, testing is most important as the preferences concerning design solutions can be tested and evaluated with real users. Usability testing can be applied to small scale user studies with rough prototypes at the concept creation stage, or formal usability testing with elaborated prototypes or semi-finished products in order to get the product details right and to see if the goals have been reached.

The prototypes were tested with stakeholders, colleagues and most importantly with users. Models and prototypes can be high or low fidelity. High fidelity models are finished and detailed and resemble final product closely. Low fidelity models are visually rough or represent only certain features of the product. Virzi et.al. (1996) argues that the usability problems can be effectively identified with low fidelity prototypes that will drive the innovation process:

"The user experience (UX) is the totality of user's perception as they interact with a product or service. These perceptions include effectiveness (how good is the result?), efficiency (how fast or cheap is it?), emotional satisfaction (how good does it feel?) and the quality of the relationship with the entity that created the product or service (what expectation does it create from subsequent interaction?)" (Kuniavsky 2010, p:14).

Identification of usability and acceptance dimensions for temperature sensor socks

Totter et.al. (2011) used the term 'dimensions' from Fensli and Boisen (2009) to describe the user's experience and feeling of wireless sensors. These are sensor efficiency and reliability, medical aspects, wearability and affective aspects (Totter et.al. 2011). This study does not address the diagnostic part of temperature sensing socks; accordingly, the two dimensions were chosen to review the wear trial results were wearability (SW) and affective aspects (SA).

Wearability (SW) is evaluated by studying the daily comfort during physical activities. The fitting of the TSS is an important attribute to determine the overall wearability of the socks, and the two attributes measured in this dimension were comfort and fitting. Affective aspects

(SA) the perceptions of wearing the sensors, depends on social acceptance, personal style and look. The image aspects, personal identification and motivational aspects were also evaluated.

Wear trial and focus group were used for data collection. The empirical data from the wear trial was discussed in the focus group involving the developers of TSS, participants, designers and academic researchers. The focus group discussion emphasised the wearability and affective aspects of the socks that could contribute to research that will drive the innovation process and identify sales opportunity for the socks.

Data collection and analysis

The wear trial used six participants, two men and four women, aged 28-48. Individual participants were given general information about the TSS and clearly explained that diagnostic part of the socks not tested and the sensors were not activated. Each participant was given two pairs of socks: pair A without sensors and pair B with sensors. Socks with sensors and without sensors were kept anonymous from the participants in order to measure variation in wearability dimension between the two pairs. UK size 7, TSS were used for experiments, and the shoe sizes of participants were between UK size 5 - 9.5. The fibre content of the TSS used for the experiment were 50/50 white polyester cotton. Two wearer assessment forms for each types of sock were given to participants to record their wear trial experience.

The socks were worn by each participant for 100 hours split evenly between the two types. The wearers were asked to answer questions related to wearability and affective aspects for both pairs of socks, before and after wash and explain their experience using photographs. Participants were advised to wash the socks in 40°C and no tumble dry. A Likert scale was used to measure the participant's acceptability of TSS socks before and after wash.

Wearability dimension (SW)

The two attributes in this dimension were comfort and fit. The comfort attribute factors were easy to put on and take off the socks, widthways stretch, physical irritation (due to sensor abrasion) and overall comfort. The comfort factors before and after wash of pair A and pair B were charted in figures x and y.

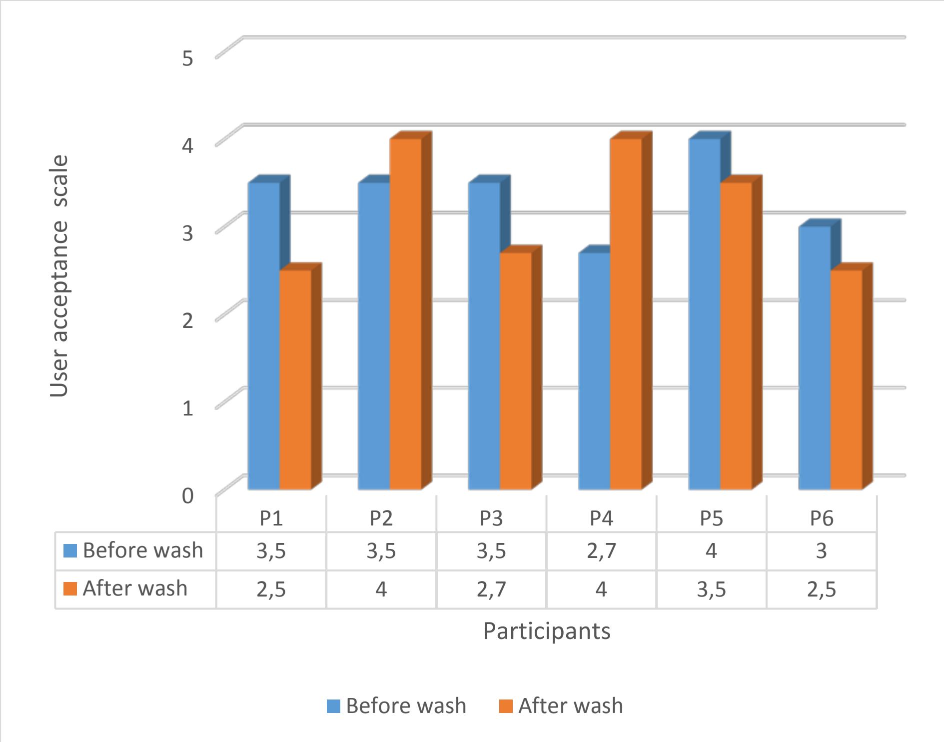

Figure 4 Comfort factors of Pair A (without sensors) before and after wash

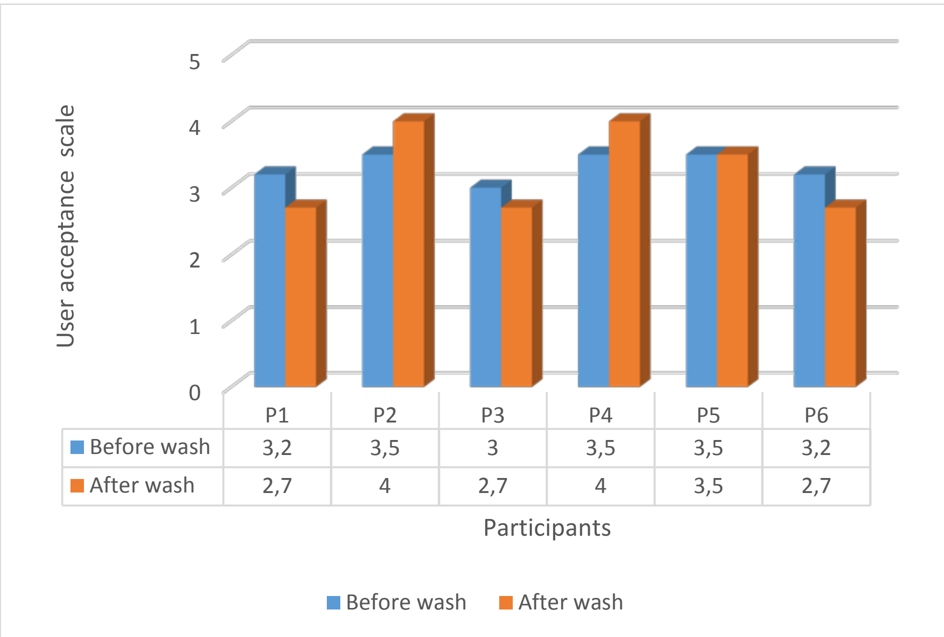

Figure 5: Comfort factor of Pair B (with sensors) before and after wash

The problems identified by participants of wear trial related to comfort started on the first day when five of the participants found it difficult to put the socks on. The four female participants were unhappy with the overall fit of TSS before and after washing. On the second day, the socks were loose at the ankle even before laundering. However, as the socks became floppy they became more comfortable, but this also caused the sensors to move away from the sensor points under the feet. Conversely the top rib became tighter after each wash which made them more difficult to take on and off. All participants complained about the size of data processing box and its placement. They had to remove the data processing box in order to put on the socks and the hand sewn pockets frayed after first wash.

The participants were not happy with the fiber content and the thickness of the socks in the sole where they are woven in knitted channels. Four female participants experienced discomfort from the sensation of wearing them and from itchy sweaty feet. The physical irritation factor was described as

"….the socks felt 'granular' the feeling was not uncomfortable, but more like wearing a fitness sole that is indented to massage the base of the feet. But at the end of the day I was really pleased to take the socks off and not to feel the lines of pressure underneath my feet ".

The factors under fit attribute: fit at the heel and ankle, top rib and overall fit. The fit factors before and after wash of pair A- without sensors (figure 6) and pair B- with sensors (figure 7) were plotted in two charts.

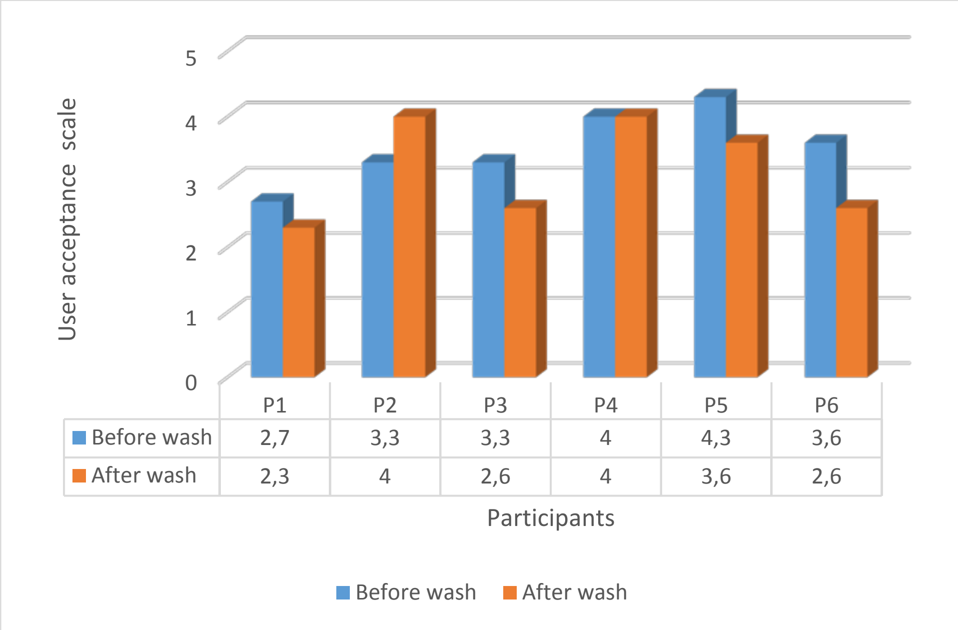

Figure 6: Fit factors of Pair A (without sensors) before and after wash

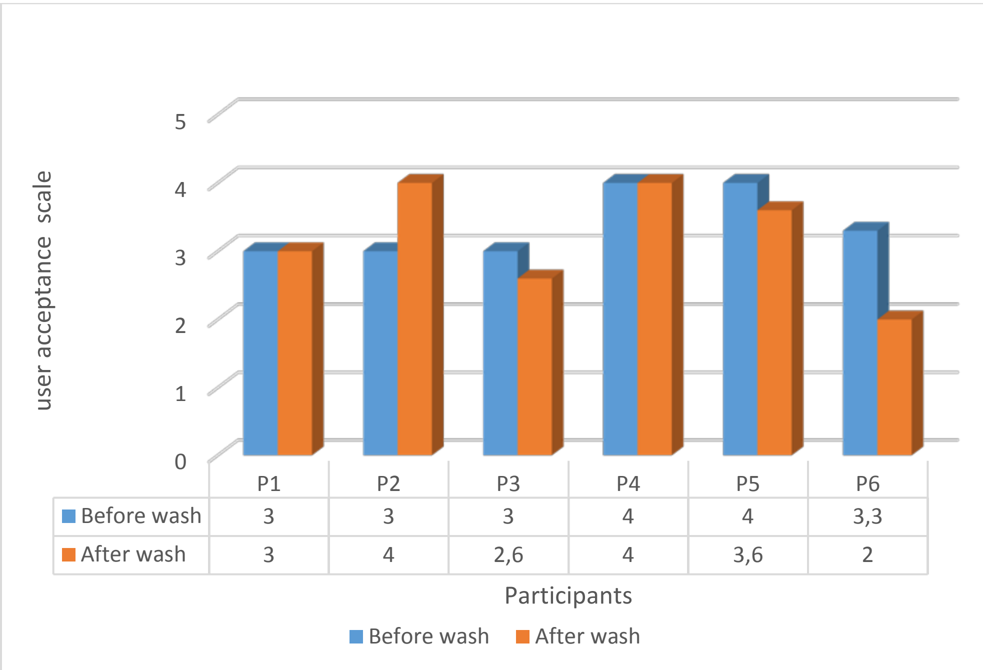

Figure 7: Fit factor of Pair B (with sensors) before and after wash

Affective aspect (SA)

The factors under affective aspects were personal style, look and feel (overall appearance), and motivation. The affective aspects before and after wash were plotted in the charts (figure 8):

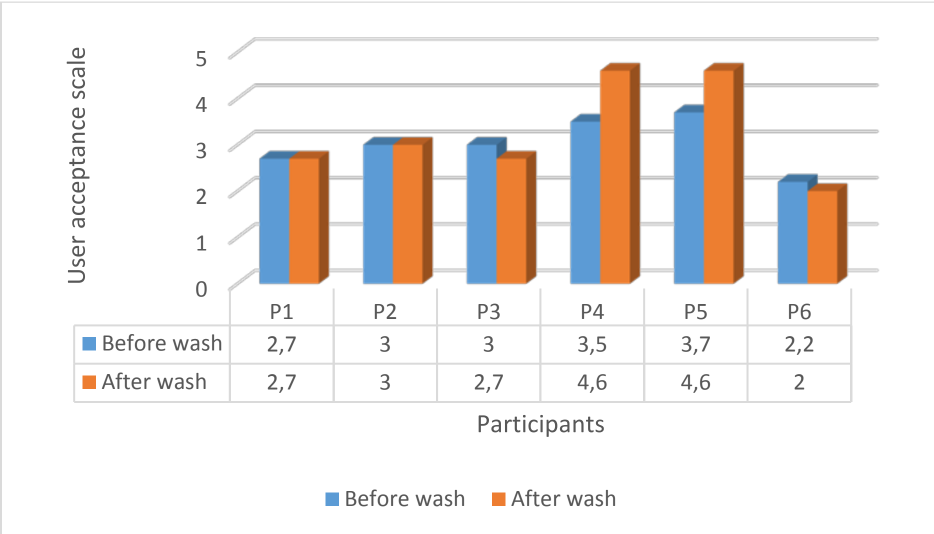

Figure 8: Affective aspect factors of Pair A (without sensors) before and after wash

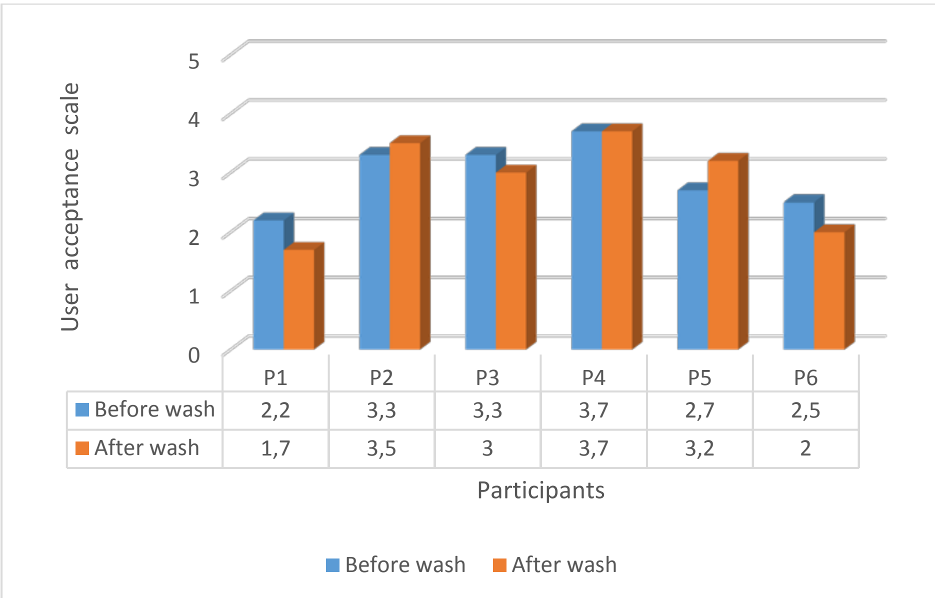

Figure 9: Affective aspects factor of Pair B (with sensors) before and after wash

Participants were not happy with the overall appearance of the socks. Some participants wore additional socks to cover the data processing box and it prevent it from slipping from the pocket and velcro was used as a temporary solution to stop the dummy data processing box slipping out of the pocket. The female participants were concerned about choice of clothing due to the unsightly bulge of the data processing box; consequently the socks were only worn with trousers. All participants agreed that the socks lacked styling, with one commenting that:

"*…even though they are not socks for fashion, I think because of what that represent they must be visually appealing, so that the wearer does not feel that, she is wearing it only because of the medical implications*".

The socks were white, which made it difficult to remove the stains and they had heavy pilling at the bottom and ankle.

Validation of the wear trial

Since the wear trial was an evaluation process for TSS it was important to discuss the trial results with potential stakeholders to validate the method applied. A focus group of six male and four female stakeholders was organized, purposively selected as developers of the socks, designers, fashion marketing researchers and from the wear trial. The event included presentations of mockup samples of TSS used for the wear trial, original samples of TSS, a design process book of TSS mock samples and a power point presentation about the TSS, it's medical application and wear trial results. The discussion was audio recorded and analysed.

The findings demonstrated a concern about the number of participants selected for the wear trial. The main constraint on numbers in the trial was the four month project time-line and that it took more than a month to complete the socks. The results of the focus group were categorised into critical elements with their corresponding user experience factors. The results were then used to validate and enrich understanding of the wearability and affect aspects of the TSS; Table 1 summaries the problems and solutions discussed in the focus group.

User experience dimension	Problems	Solutions
<u>Wearability</u>		
Fit		'Scan to knit' is a method that could be carried into this project. It would then

	TSS size 7 was a perfect fit for UK size 6 and size 9.5	make the socks into a more bespoke item Currently technologists are working on automating the complete process, not on hand crafting the socks
	The body of the socks sagged and flopped that made the heel of the socks not aligning with the wearer's foot	The fibre content and design of the socks should be revised in order to resolve the fit and comfort problems
	Fit problems will question the accuracy of reading the temperature from the feet as the sensors were no longer positioned correctly	There are certain specific points for temperature sensing under the feet. The sensors are very small chips that can sense the temperature from an area (figure 10). It is not necessary that the sensors should be placed in the exact position, a slight change in the position will not affect the reading.  Fig 10: Temperature sensing point
Comfort	Experiencing rash and itching under the feet	Further research should go into reducing diameter of the TSY to lessen discomfort while wearing the socks
	Participants with diabetics are slightly older profile and have problems getting their socks to feet	There are socks in the market that are designed with fairly loose structure like M&S fresh feet non elastic socks. They are designed well with beautiful patterns.

		Technologists can collaborate with professional socks companies to rectify the design problems
Affect aspect		
Style (look and feel)	The styling of the socks was not up to the participants liking	The design of socks should be completely revised in order to market the product
	How do we make the data processing box acceptable for the wearer?	The sensor devices could be embedded in an insole that could be placed into the shoes. The data process unit and the batteries could be placed under the longitudinal arch of the feet where there is no pressure. Another proposed solution was proximity sensing that could be in the insole which then senses the temperature changes
Personal identification	In order to collect data, the participants have to install a specific application in their phone. If cost is implied for an app, then that should be considered. If you share an app then there is an issue of data sharing	Along with the technology and design developments, data security is an important issue that should be taken to consideration
Marketability	The socks used for trial were handmade and lot of work was put into it, that automatically increases the price of the product	Price does have an impact on people's acceptability of the product. It is important how we communicate the benefits of the socks clearly to the consumers. The consumers are often
Price		

	Mass production in Asian countries made cheap price expectations for socks	willing to pay premium price if they can see the real benefits of the product
Selling point	Identifying the main technology aspect of the socks	The technology developed for temperature sensing yarn can be used in something other than the socks
Endorsement	Because it is a health care related product it needs professional endorsement	When technology is related to health, it is a serious topic. It needs professional endorsements from the national health service, diabetics groups and leading diabetic charities that will give the credibility required for TSS

Findings

The temperature sensing socks (TSS) demonstrates a significant scope for temperature sensing yarn (TSY) in healthcare. However, the ability to attract consumers to adopt this technology is crucial for technology developers and designers. The project explored the physical factors that affect consumer's adoption intentions towards smart textiles in healthcare and the implications for product design. The product should be easy to use and without obstructions; the materials should be soft and comfortable, the products designed using smart textiles should be wearable and aesthetically appealing to encourage use.

Studies about wearable health care devices have conceptually stated some critical factors or experimentally examined a limited number of important factors from technology perspective (Claes et.al. 2015; Steele et.al. 2009). This research empirically investigates user experience of smart textiles in health care. Moreover, the trial reveals that socks with sensors (pair B) caused skin irritation for some participants. However, male and female participants provided different feedback from the trial. The male participants were satisfied with the wearability (SW) of the socks and not happy with affect aspects (SA). On the other hand all four female participants were unsatisfied with wearability (SW) and affect aspects (AS).

Apart from the technology perspective, the study explored factors that influence the consumer's intention to adopt smart textiles in health care and privacy perspectives, which is expected to provide assistance for future smart textiles research. This research indicates that future empirical studies about smart textile adoption in health care should consider factors from multiple perspectives such as technology, data protection, collaboration with professionals in health care sector, product designers and potential end users.

Conclusion

In seeking to 'break the rules' of fashion this paper has explored the role of new technologies in smart textiles. First, it enables new questions to be asked about fashion in the conceptualisation of communicative wearables and the problem of language, to define – using a material cultural term – stuff. While socks were designed for the project, they are clearly not conventional socks, in a small part because of the smart textile itself, but largely because of the need to accommodate the communication and battery unit. So the functionality of the TSS at this stage of development contributes to the design of a different sock-like object. 'Affordances' can be used to describe actionable qualities of design in an environment, and in this study the generally accepted affordance of a sock has been extended by both its qualities and environment. The hidden communicative qualities of its smart textile itself and the more visible if enigmatic added power supply pocket. The conventions of a 'sock' as a foot covering for comfort, hygiene and social acceptability, were modified by the need to communicate changes in foot temperature.

Moreover as technology replaces many of the designers' tasks, new models of consumer awareness of global fashion trends are required to facilitate the design of the final product. As the focus group demonstrated, consumers are willing to pay a premium price if the product can satisfy their functional and aesthetic needs. In this case, designs that account for the aesthetic requirements of the consumer will encourage adherence to its medical use (Bush and Kent 2017).

Second, the rules are challenged by the interdisciplinarity required to integrate smart technologies with fashion. From the outset of a smart textile project this may involve an understanding of textiles, information technology and engineering disciplines, a need to work within the constraints they impose and different approaches to teamwork. The whole concept of a fashion project may change, for example with the need to access experimental materials and equipment situated in another discipline. In this project, the samples had to be hand-made so the possibility for rapid prototyping did not exist, and opened up new possibilities for fashion as crafting and materiality.

Finally, the project challenged the conventions of fashion education through its focus on healthcare and more general wellbeing. Healthcare products tend not to be found in the mainstream of the fashion industry and if wellbeing is to become a more important element of fashion, then it needs to find a particular place in the curriculum. By researching the development of a new product for monitoring diabetes, this project can contribute to the design of fashion courses and their content, and more profoundly to the boundaries of fashion.

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