Lessons Learnt from Designing a Smart Clothing Telehealth System for Hospital Use

Deepti Aggarwal
HAFP Research Lab, School of Design, RMIT University, Australia

Thuong Hoang
School of Information Technology, Deakin University, Australia

Bernd Ploderer
Electrical Engineering and Computer Science, Queensland University of Technology, Australia

Frank Vetere
School of Computing and Information Systems, University of Melbourne, Australia

Rohit Ashok Khot
HAFP Research Lab, School of Design, RMIT University, Australia

Mark Bradford
Department of Anaesthesia and Pain Management, Royal Children's Hospital, Australia

Figure 1: SoPhy in action: A physiotherapist is using the SoPhy interface to understand the movements of a remote patient in a video consultation. The patient is wearing the SoPhy socks to demonstrate her improvement in walking.

ABSTRACT

In this paper, we describe the design journey of a smart clothing system, *SoPhy* from the research laboratory to finally being evaluated in the hospital setting. *SoPhy* is a smart socks-based system, designed to make physiotherapy video consultations effective for assessing lower limb issues. *SoPhy* is the result of a 3-year journey of development, study and refinement of a research prototype done in collaboration with a physiotherapist. Drawing on this journey, we present seven lessons that emphasize on the importance of fostering strong collaborations with clinicians to move beyond laboratory studies and reach the target health setting. We provide contextual narratives on how we designed a comfortable smart clothing for patients; how we created an intuitive mapping of sensor data for clinicians; how we integrated hospital practice in the system design, and how we managed the ethics clearance for the field evaluation. We hope that these lessons are useful for HCI and health researchers who aim to innovate the field of health but feel restricted with the little knowledge of design and electronics.

OzCHI '20, December 02–04, 2020, Sydney, NSW, Australia

ACM ISBN 978-1-4503-8975-4/20/12…$15.00
https://doi.org/10.1145/3441000.3441033

CCS CONCEPTS

• **Human-centered computing** → Interaction design; Interaction design process and methods.

KEYWORDS

Telehealth, Video Consultations, Smart Clothing, Physiotherapy, Digital health

ACM Reference Format:

Deepti Aggarwal, Thuong Hoang, Bernd Ploderer, Frank Vetere, Rohit Ashok Khot, and Mark Bradford. 2020. Lessons Learnt from Designing a Smart Clothing Telehealth System for Hospital Use. In *32nd Australian Conference on Human-Computer Interaction (OzCHI '20), December 02–04,* *2020, Sydney, NSW, Australia.* ACM, New York, NY, USA, 13 pages. https://doi.org/10.1145/3441000.3441033

1 INTRODUCTION

Recent advancements in sensing and wearable technologies have prompted an increased interest in exploring digital methods and tools that can support effective assessment and treatment of patients within healthcare sector [9, 17, 24]. Smart clothing is one such promising area that is gaining popularity because it could enhance "*our capabilities without requiring any conscious thought or effort*" [25]. This interest in smart clothing is governed by the inherent properties of a clothing such as being personal, comfortable, adhered to the skin, and easy for use almost anywhere and anytime [13], which makes them ideal for assessment and monitoring of patient's conditions. Smart clothing systems embed different sensors within their clothing line to capture useful data about the wearer such as physiological signals or movement patterns [13, 25]. The captured data can then be communicated to the patients for self-reflection or to their clinician for diagnostic purposes.

Despite the growing interest, little efforts have been made to design smart clothing systems for health settings, particularly for physical rehabilitation. On the commercial front, several companies such as Sensoria, Wearable X and Wareable have developed smart clothing systems like smart shirts and smart yoga pants for fitness tracking; However, these systems generally target healthy individuals and they are yet to reach wider mainstream. On the other hand, within HCI, majority of the technological explorations to support rehabilitation bear the form of bands that patients can wear around the affected body part (refer review article by [29]). Wearable bands, however, have certain limitations when it comes to using them for body parts like feet or elbows [19, 38]. As noted by [38], wearables are more suitable for rigid body parts that are relatively stable, have flesh and are towards the body's center of gravity. For moving body parts such as feet, they struggle to capture accurate data. Besides, wearable bands cannot offer the same level of comfort and flexibility that a clothing can offer especially in healthcare, where patients may have injury, swelling or pain in the body part that needs monitoring. A smart clothing system that combines the accuracy of wearables with the comfort of a clothing thus becomes a more suited option for healthcare.

Developing smart clothing for healthcare is however challenging because of its multidisciplinary nature that require one to either collaborate or possess knowledge of engineering and design (i.e., hardware, software, textile design), as well as the desired context of use (healthcare, hospital settings). In hospital settings, patients often battle critical health conditions that require extensive care and these conditions also affect their everyday lives and their sense of self. Given the high stakes, there is little room for technical failures or inaccuracy that often characterize early HCI prototypes [11, 18]. Besides, clinicians typically have significant workloads and their priority is to care for their patients, rather than spending time in designing and evaluating new technologies. The hospital environment also requires adherence to strict hygiene standards, which can be challenging for smart clothing containing electronic components that could get damaged with washing or coming in contact with water. Finally, healthcare settings also work with specific rhythms of consultations and schedules and their functioning is constrained by larger infrastructures that govern the funding, technology infrastructures, professional and ethical standards, as well as strict legislation [9, 11]. Hence, it is not surprising when Blandford [10] states that HCI health technologies rarely go beyond laboratory evaluations, and more guidance is needed to understand the deployment and evaluation of HCI health research prototypes in hospital settings, which this paper aims to address.

In this paper we elucidate the journey of a smart clothing system – *SoPhy*, from an HCI research prototype to finally being evaluated in a large pediatric hospital in Melbourne. Our reflections are based on the development and field deployment of *SoPhy* in real-world physiotherapy consultations conducted both face-to-face and via telehealth (over video). *SoPhy* is a smart clothing system [2] that captures lower body movements related to weight distribution, foot orientation, and range of movement, which are otherwise challenging for physiotherapists to observe in video consultations (refer Figure 1). *SoPhy* consists of two parts: (1) a pair of socks that captures a patient's lower body movements, (2) and a web-interface that visualizes the captured information to a remote physiotherapist in real-time. We developed *SoPhy* to support the tasks of physiotherapists at the collaborating hospital, where physiotherapists organize regular video consultations for their patients with chronic pain conditions.

While our previous works described *SoPhy* system [2] and its efficacy from clinicians' perspective [3], we have written this paper to provide lessons learnt for HCI researchers that often go unreported, i.e., the challenges and insights from the development of a prototype to lab evaluation and finally to hospital deployments. Through these lessons, our aim is to help HCI researchers and designers to understand the potential and conduct of collaborating with clinicians, and the complexities and key factors involved in designing for health settings. We hope that these lessons will guide more collaborative explorations between HCI researchers, health practitioners and patients to create technologies for real-world impact.

2 BACKGROUND & RELATED WORK

Cho [13] described that a smart clothing consists of the following elements: (a) an interface that allows users to provide input and output; (b) a communication channel that supports the transfer of data between smart clothing and other devices via Bluetooth or Wi-Fi, (c) a data management component for the required storage, computation and data processing; (d) an energy management component such as a battery to power the system, and finally, (e) integrated circuits made up of semiconductor materials that help in embedding the required intelligence in the clothing. Since smart clothing is a form of computer, it should also satisfy the inherent properties of both a computer technology as well as a clothing. To this end, a smart clothing should support the following six factors [13]: (1) Usability: It is the characteristic of a computer technology, where the system should be easy to use and should involve few errors in accomplishing the given task. (2) Functionality: It is the characteristic of a computer technology, which means that the system should fulfill the specific purpose for which it is designed. (3) Safety:

It is the characteristic of a computing technology, which means that the system should be safe against overheating, electric shocks, electromagnetic waves and other hazardous conditions. This factor involves both physical and psychological safety. (4) Durability: It is the characteristic of a clothing which means that the smart clothing should be able to withstand repeated use, abrasion and laundering. (5) Comfort: It is the characteristic of a clothing, which means that the smart clothing should be convenient in wearing and that the wearer should not feel any difference in doing the activities while wearing it. (6) Fashion: It is the characteristic of clothing, which means that the smart clothing should aesthetically look good.

On the other hand, Gemperle and colleagues [19] described thirteen guidelines that should be considered while designing a wearable technology. These guidelines include: (1) the placement of device on body, (2) form of the device, (3) movements in the concerned body part, (4) human perception of space, (5) diversity in body sizes, (6) device attachment on body, (7) containment of the device, (8) weight of the device with respect to the body part, (9) physical access to the device, (10) sensory active and passive interactions with the device, (11) thermal tolerance of the device, (12) aesthetics of the device, and finally (13) long term use of the device. After twenty years, Zeagler [38] revised the guidelines of Gemperle and colleagues [19] based on the advancements in electronics for wearable technologies. The researcher provided detailed mappings on different parameters of wearables such as placement of the form on body, appropriate size of the device for different body parts, and appropriate weight of the form for different body parts, to guide further development of wearable technologies. Since smart clothing comes under the umbrella of wearable technology, these guidelines are also applicable for designing a smart clothing. While all these frameworks are helpful in designing a smart clothing, it is unclear how designers and researchers incorporate them during the design process; and whether and how they prioritize different factors based on the project needs at different times of the development phase. Besides, how do these factors play out in health settings, where patients are in pain, clinicians have busy schedule and there is little room for experimentation.

In health setting, Blandford, Furniss and others [9, 11, 18] have extensively described the challenges of working in a hospital setting and emphasized the values of human-centered approach to design new technologies. For instance, the researchers have described different strategies for collaborating with hospitals and clinical staff and maintaining a healthy relationship; understanding the hospital practices for getting ethics clearance; making best use of the limited availability of the clinical staff; and making both the researchers and clinical staff comfortable with the research aims and methods. However, little is known how researchers manage to take the research prototype in hospital setting for real-world use; what roles clinicians can play in the design of a prototype; and how to design for the hospital practice and protocols. The lack of clear design guidelines motivated us to share the knowledge that we gained from the development of a smart clothing that is designed to support physiotherapy video consultations. Before we describe our system, we offer a brief overview of what physiotherapy video consultations are and current explorations in this space.

2.1 Technologies for Physiotherapy Video Consultations

Physiotherapy, also known as physical rehabilitation, focuses on improving people's ability to move and do everyday activities [7]. Physiotherapists observe subtle differences in the patient's movements, e.g., smoothness in the exercises and weight distribution patterns, to understand their recovery and to plan the therapy goals. Physiotherapists check the patient's full body posture, positioning of the back, hip and feet, and also conduct a physical examination by touching the affected part. While these subtleties are easier for physiotherapists to observe in collocated settings (i.e., face-to-face consultations), they are challenging to interpret in video consultations [1].

In Australia, physiotherapists are increasingly conducting video consultations to meet the needs of patients living in remote and rural areas [8]. The recent pandemic has further increased the reliance of clinicians on video consultations all over the world [20]. In a video consultation, patients and physiotherapists use video conferencing tools like Skype for the purpose of diagnostic and therapeutic advice [37]. Our previous study [1] illustrated that video conferencing tools like Skype alone are not sufficient to support the clinical needs of physiotherapists, as they do not mediate a wide variety of bodily cues. This limited understanding of the patient's movements over video reduced the diagnostic confidence of the physiotherapists and made their treatment less effective in terms of exercises (ibid).

HCI researchers are therefore, exploring the use of interactive technologies to make video consultations effective. Mentis and colleagues [27, 28] investigated the use of Google glasses to support organ transplantation surgeries between two remote surgeons over video. Google Glasses mediated the first-hand view of the task-at-hand, i.e., organ undergoing transplantation, and supported rich bodily information like eye gaze and gestures around the task. Access to the bodily information facilitated effective co-construction of knowledge and real-time decision-making between the surgeons. Similarly, Stevenson [32] used multiple webcams and a pen-and-tablet system to support rich interactions in surgery related video consultations. The researcher described that the pen-and-tablet system helped in mediating gestures around the patient's digital records, which in turn provided patients with a better understanding of their symptoms and treatment. Besides, multiple webcams supported rich bodily information related to body orientation, eye gaze and attention space of the participants. These works present important insights on how to enhance the conduct of clinical tasks in video consultations, however, they are not related to physiotherapy consultations.

While there have been limited technical explorations for enhancing clinician-patient interactions in physiotherapy related video consultations, there exists a significant literature on supporting physical rehabilitation of patients [29]. Majority of these investigations aim to support patients at home during the rehabilitation program or post-program to help them maintain their active routine in the absence of physiotherapists [4, 12, 15, 31, 35]. While some technologies provide ways to connect patients and physiotherapists remotely [6, 15, 23], none of them is explicitly designed or evaluated to support clinician-patient interactions in video consultations of physiotherapy. The existing systems can be classified into two categories: environmental tracking and on-body tracking.

In environmental tracking, patient's movements are monitored by arranging sensing technologies in the surroundings. Commercially available technologies like Playstations camera, Microsoft's Kinect and Wii-Fit Board are some examples of systems that have been used to track patient's movements [29].These systems although were not developed specifically for clinical purpose, their low maintenance cost and ease of deployment have made them a popular choice to understand the specifics of body movements. Along the similar lines, Physio@Home [35] is a system that utilises multiple Vicon motion tracking cameras to support arm and shoulder rehabilitation of patients at home. The laboratory evaluation of the system with healthy participants highlighted that the system guided accurate movements and participants performed least errors in the presence of visual feedback offered by the system. Although environmental tracking has benefits of being non-intrusive, it has issues related to capturing dynamic movements and accurately capturing certain body movements. For example, Wii board is suitable for standing postural exercises but cannot capture dynamic movements like walking. On the other hand, the depth sensors of Kinect have limitations in accurately capturing the fine-grained movements, particularly, related to lower limbs [22, 29, 36].

To overcome the challenges of environmental tracking, researchers have explored on-body tracking, where the sensing units are directly attached on the patient's body to track their movements. One common form for these systems include sensing bands that patients can fasten to monitor movements of their affected parts. For example, ArmSleeve [30] is one such system that aims to support the clinical tasks of occupational therapists by providing them information of how much patients undergoing stroke rehabilitation use their upper limbs in daily life. The sensing unit consists of three bands that patients put on the wrist, elbow, and arm and shoulder joint, of the affected arm. Similarly, Go-with-the-flow is another system that is designed to improve the quality of life of patients having chronic lower back pain by providing them audio feedback on their everyday activities [31]. The system consists of two bands that the patient wears to monitor the movements. Rehabilitation Visualisation System (RVS) is another system that provides real-time feedback about the range of motion of patient's knees [6]. PT Viz system [5] also detects the bend angle of the knee, but it provides the visual feedback directly on the wearable. Along the similar lines, Automated Rehabilitation System (ARS) is another system that helps physiotherapists in the clinic to monitor the recovery of patients undergoing knee and hip replacement [23]. ARS consists of a sensing band with inertial measurement units that captures the patient's posture and presents visual feedback as an animation overlaid on the instructed motion visuals of the exercise. Evaluation of these systems have shown promising results on patient's recovery and their motivation to continuing an active routine.

While academic explorations are mainly limited to band shaped wearables [14], several companies are developing smart clothing and accessories to make on-body tracking more comfortable and seamless. For instance, Sensoria socks and shoes are commercially available systems that capture information related to the walking and running pattern, e.g., speed, pace, cadence and foot landing along with physiological signals like heart rate and blood pressure. The captured data is presented on a mobile app to support post-activity reflection. Although these systems are not specifically designed for clinical use, they can be beneficial for people having lower limb issues. For instance, a comparative study of the Sensoria socks and gait system traditionally used in the clinical setting highlighted that the data captured by the socks is comparable with the gait system [33].

In summary, the existing systems demonstrate the significant potential of wearable technologies to support physical rehabilitation for patients, none of these systems are however, designed specifically for video consultations. Additionally, less efforts are made to develop and evaluate systems for lower limb rehabilitation specially related to legs and feet, which are particularly more challenging to assess over video [1]. For instance, the subtle differences in lower limb movements such as weight distribution and range of foot movements are not mediated by the current video conferencing tools. Also, focusing the camera on lower body is not a feasible option as it limits other crucial bodily cues such as full body posture and facial expressions (ibid.). As such, assessing lower limb issues requires a significant understanding of the subtle differences both in the affected body part as well as of the full body movements.

We designed *SoPhy* to support the needs of physiotherapists in assessing and treating patients with lower limb issues during video consultations. *SoPhy* was first evaluated in the lab with physiotherapy students [2] and then at a pediatric hospital with chronic pain patients [3]. This paper reflects on the lessons we learnt across different phases, from development to lab study and finally to field evaluation of *SoPhy*. We describe key design decisions that made *SoPhy* a useful tool for both patients and physiotherapist at the hospital. Before describing the lessons learnt, we first describe the design of *SoPhy*.

3 SOPHY: OUR SYSTEM

SoPhy (*So*cks for *Phy*siotherapy) is a smart clothing system designed to support lower limb assessment and treatment of patients in physiotherapy related video consultations. It has two parts: (1) a pair of socks for the patients containing three pressure sensors placed at the sole and one Inertial Measurement Unit (IMU) attached on the bridge of the foot (Figure 2a); (2) a web-interface that presents information related to weight distribution, foot orientation, and range of movement to physiotherapists in real-time (Figure 2b). Weight distribution is the amount of weight a person is bearing on different parts of the foot e.g., on toes, balls and heel. Foot orientation refers to the alignment of the foot in all four directions. Finally, range of movement refers to the angular displacement of foot in the upward (dorsiflexion) and downward (plantarflexion) position.

In a video consultation, when the patient performs the prescribed lower body exercises (e.g., squats, tip toes and walking) wearing the *SoPhy* socks, the physiotherapist can see the movement related information in real-time on the *SoPhy* web-interface (refer Figure 1).

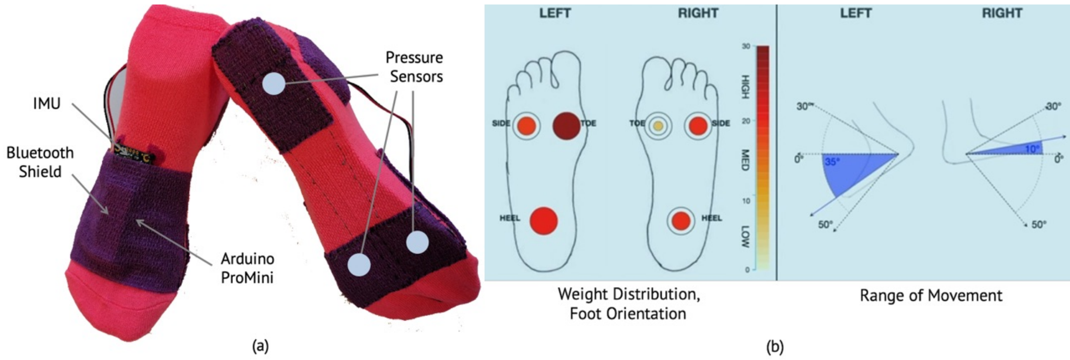

Figure 2: SoPhy system consists of two parts: (a) A pair of socks with sensors attached on the sole and bridge of the foot to capture lower body movements of the patients. (b) A web-interface that presents visualization related to weight distribution, foot orientation and range of foot movement.

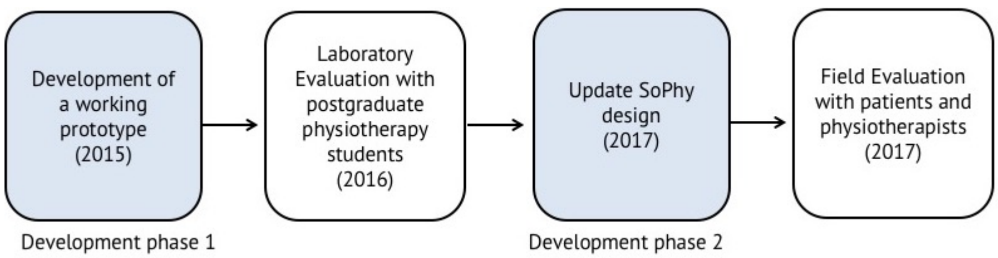

Figure 3: Different phases of the project: *SoPhy* was developed in two phases. The system was first evaluated in the lab settings before evaluating it with real patients at the hospital.

3.1 Design process

The idea of developing *SoPhy* was initiated in collaboration with the Pain Management team of a pediatric hospital. The design process began in the year 2015, was followed by a laboratory evaluation, then followed by reiteration of the design and finally led by a field evaluation at the collaborating hospital in 2017 (refer Figure 3). We employed the human-centered design approach to develop *SoPhy*. We worked closely with a physiotherapist (last author) from the collaborating hospital to understand the needs of clinicians and patients in video consultations. At the time of the development, he had 25 years of practice experience, and was organizing regular video consultations from five years at the collaborating hospital. The collaborating physiotherapist was involved in all the phases of the project. Table 1 shows the role of the collaborating physiotherapist across different phases. The design process was led by an interdisciplinary team consisting of Computer Science Engineer, Electrical and Electronics Engineer and Interaction Designers.

During the design phase, we explored several technologies for capturing body movements, however none of these technologies directly fulfilled our needs. For instance, the existing computer vision-based systems such as Microsoft Xbox Kinect and Vicon motion tracking cameras, have limitations in precisely capturing the subtleties of movements related to the lower body, and hence were discarded [22, 36]. Similarly, we did not consider the commercially available devices like pressure mats, Wii-Fit board because they were not sufficient to support the dynamicity of the physiotherapy sessions. For instance, in a physiotherapy session, patients perform a wide variety of exercises ranging from sitting down on the chair to lying down on the floor [1] – these exercises are not possible with Wii-Fit board. Moreover, we also did not have the option to customize commercially available Sensoria socks and in-sole shoes because their API was not open to use during the design phase of this project. Finally, we chose to design a pair of sensing socks because: (1) socks are lightweight, hence comfortable to wear during exercises. (2) Socks conform to the body, hence can precisely capture fine details of the body movements. (3) And lastly, socks move along with the patient and is therefore, suitable to capture a wide variety of movements like sitting, walking, squats and hopping.

The development happened in two phases. In the first phase, the socks and web-interface went through multiple iterations to develop a functional system. This phase was followed by a laboratory evaluation, where we evaluated the use of *SoPhy* with postgraduate physiotherapy students. Figure 9 shows the version of *SoPhy* that was used in lab study. To understand the utility of *SoPhy* for physiotherapists, we simulated the setting of video consultations across two rooms and compared the use of *SoPhy* against the standard video consultation practice. Details of the design rationale and laboratory evaluation are available in [2]. This study confirmed that *SoPhy* enhanced the ability of participants in assessing lower body movements over video. The study also highlighted certain issues with *SoPhy* that motivated further refinement of *SoPhy*.

Table 1: The project started with the development of SoPhy and concluded with the field evaluation. The collaborating physiotherapist was involved in all the phases.

Phases	Role of the physiotherapist
Development 1	•Discussion on the relevance of the chosen bodily cues •Discussion on the placement and calibration of sensors for different foot sizes •Role playing as a patient and physiotherapist to check the use of socks •Feedback on the visualization and web-interface layouts
Lab evaluation	•Feedback on the study design and questionnaires developed for data collection •Discussion on the issues found in the lab study and brainstorming the potential solutions
Development 2	•Role playing as a patient and physiotherapist to check the use of SoPhy •Feedback on the iterations of socks and visualization layouts
Field evaluation	•Managed the review of ethics application by different departments within the hospital •Feedback on the study design •Assistance in getting access to hospital resources like rooms, computer systems and Wi-Fi access, for conducting the study

The second phase aimed at resolving the issues discovered in the laboratory evaluation and in preparing the system for field deployments. Both the socks and web-interface went through another set of iterations. Finally, the system was evaluated in real video consultations at the collaborating hospital, where it was used by the collaborating physiotherapist and three patients for five months [3]. Figure 2 shows the version of *SoPhy* that was used in field study. All patients had different chronic pain condition associated with lower limbs. *SoPhy* was used in six consultations: the first patient used *SoPhy* in two consultations, the second patient used it in three consultations and the third patient used the system in one consultation. The collaborating physiotherapist not only recruited these patients based upon their needs and suitability to try the system but also decided when to use the system with every patient. This study highlighted that *SoPhy* increased the diagnostic confidence of the physiotherapist and guided more accurate assessment of the patients. Also, it helped both the physiotherapist and the patients to refine the therapy goals and make them more appropriate to the patient's current health status.

We also acknowledge that much more efforts are required to see *SoPhy* becoming a part of clinical practice at hospitals. We were able to conduct a field study of *SoPhy* in a hospital setting, through which we could understand how the system fits the needs of the physiotherapists, patients and care context. However, this is only the first step towards changing clinical practice. As discussed by Blandford [10], further work is required to move from successful HCI research towards clinical practice. Crucial next steps include further research to establish the clinical effectiveness and cost-effectiveness of *SoPhy* at a larger scale, to establish that the medical device is safe through FDA approval, and to integrate the system with the existing clinical systems.

4 OUR REFLECTIONS

Based on the knowledge gained from the development of *SoPhy* as well as from the evaluation of *SoPhy* both in lab and hospital settings, we discuss 7 lessons to guide further development of smart clothing for healthcare.

4.1 Prioritize patient's comfort over aesthetics

Comfort and aesthetics both are key parameters for smart clothing and wearable technology [13, 19]. In our design, we prioritized patient's comfort over aesthetics because the system was meant to be used by patients who are already in pain. Patients with chronic pain are cautious to try new things on their affected body part due to the fear of discomfort or pain. Our decision to develop a comfortable pair of socks informed our choice of socks (refer Figure 4 for different iterations of the socks). In the first iteration, we tried to capture pressure values on each toe to get rich data about weight distribution pattern, for which we used 5-toed socks (see Figure 4a). However, given the small surface area of toes, sewing pressure sensors on toes was challenging because it caused short-circuiting of the connections around LilyPad. Also, the 5-toed sock prototype was uncomfortable to wear, as sewing sensors on the socks made it less stretchable particularly around the toes. Having stretchable socks was an important factor because patients with lower body issues may have a swollen foot or toes, or increased sensitivity to touch. Consequently, we switched to using regular socks from 5-toed socks. The choice of socks also reduced the number of pressure sensors, and we chose three sensors: one on each ball and one on the heel (see Figure 4e for the final sock design).

Designing for comfort also influenced the choice of electronic components for developing socks. Consequently, certain design decisions contradicted with the strategies of developing a smart clothing system. As an example, we utilized Arduino ProMini instead of the microcontrollers like LilyPad that are designed specifically for smart clothing. LilyPads are visually more appealing and have more space to make thread-based connections. We tried LilyPad in the first iteration with 5-toed socks; however, its large size, circular shape a' solid printed circuit board made the sock uncomfortable. We then used Arduino ProMini as it is smaller in size, and hence supported a compact design of the socks. Besides, the rectangular shape of the board also adjusted well on the foot and did not move with any foot movements.

Using Arduino ProMini in turn, raised certain issues, which further challenged the notion of a smart clothing system. ProMini board raised the issue of short-circuiting as the pins on the board

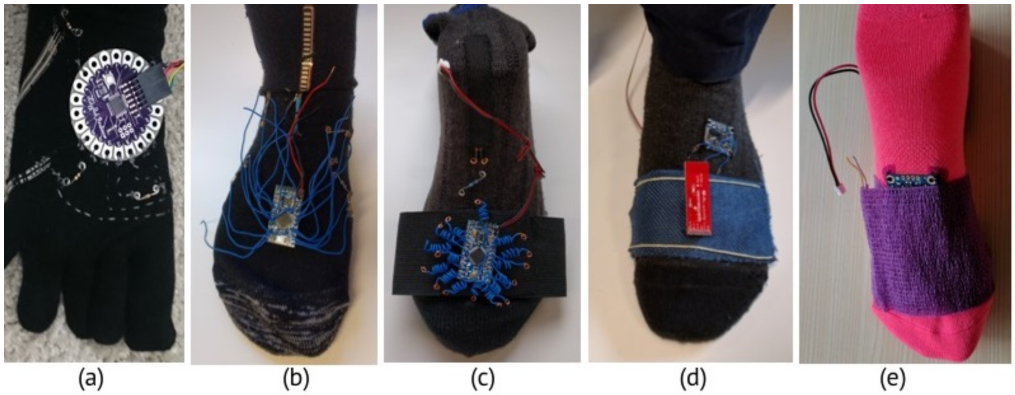

Figure 4: Different iterations of the socks: (a) The first iteration included a 5-toed sock using LilyPad. Later, we switched to normal socks and used different arrangements of the conductive wires (b) and external clothes (c). The final design shown in (e) used a combination of the conductive threads and wires.

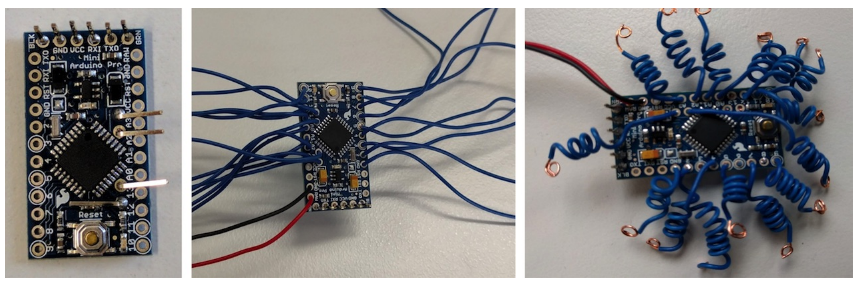

Figure 5: Arduino board was appropriated across different iterations to develop a comfortable pair of socks. Different types of extensions were made with the conductive pins (a) and conductive wires (b), (c).

are very close to each other. To create distant thread connections for the sensors, we altered the board with thin conductive wires and hard conductive pins (refer Figure 5), which contradicted with the basics of smart clothing where conductive threads are mainly used for making connections on clothes. However, the extensions on the board helped us in developing a comfortable pair of socks. We explored different ways to make connections, e.g., in one iteration, we made direct wired connections between sensors and Arduino; However, we dropped the idea because wires made the socks bulky and less appealing (Figure 4b).

In the final iteration, we used a combination of wired extension and thread connections and attached the Arduino board and other components (like resistors and Bluetooth shield) on another piece of cloth (see Figure 6). Making the connections on the external cloth made the socks more comfortable as the wearer did not feel any attachment moving on their foot. Not feeling the attachment is one of the important parameters of creating comfortable smart clothing [13]. In the field study, none of the patients mentioned any comfort issues with the *SoPhy* socks. One important point to note here is that aesthetics plays a crucial role in defining the social acceptance of a smart clothing [13, 19]. We did not explore the social acceptance as *SoPhy* was used only in the hospital and home of the patients.

Figure 6: Most of the electronic components like Arduino board and resistors were placed on an external cloth. This arrangement helped in developing both comfortable and stretchable sock prototype.

4.2 Design for varied bodies

Patients with chronic pain may have swelling in their affected body part. The swelling may differ at different times of the treatment.

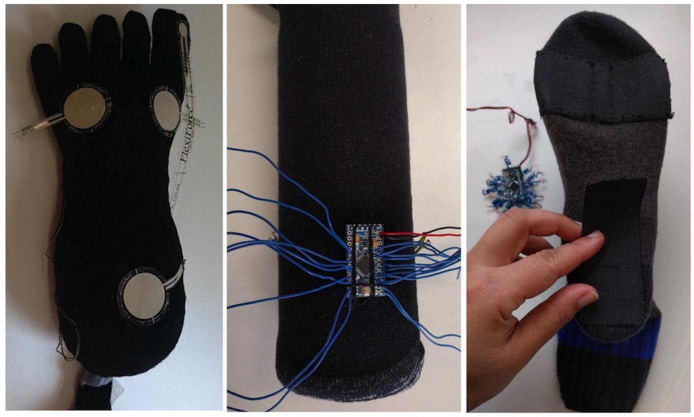

Figure 7: Examples of insertables used for sewing the socks: (a) thermocol balls, (b) water bottle, and (c) foot mannequin. Of all the three options, the foot mannequin helped in creating socks with proper location of sensors.

Hence, the smart clothing should be able to accommodate different body structures [21]. Generally, the size of the socks is defined based on the length of the foot as large, medium and small. Other factors such as the width of the foot and the length of the toes are not considered, as the socks are stretchable to accommodate different foot structures. However, they became important to consider while designing for a swollen foot. Hence, our goal was to design for different foot structures.

Firstly, we carefully chose the material of the socks that could accommodate different foot structures. We looked at different materials like spandex, lycra, elastane and nylon that are popularly used in commercial smart clothing systems. While these materials are stretchable and could support accurate monitoring of data for different foot structures, they however are not breathable. Patients with chronic pain are fearful of putting on any tight fitting or compression clothing on their affected body part. After discussing with the collaborating physiotherapist, we chose socks made of cotton material as they are comfortable and breathable.

Developing stretchable socks was a significant challenge as stretchability of a garment tends to reduce when we sew electronics on it. For developing a stretchable prototype, we used different objects to insert in the socks during the sewing trial (refer Figure 7). In the first iteration with 5-toed socks, we utilised thermocol balls (refer Figure 7a). However, the generated shape was sufficient only for a small foot size because the thermocol balls are smaller in size and are too soft to produce significant stretch. Also, the small size thermocol balls are difficult to handle, and filing them in the socks required a long time. The time investment made it problematic to test the sock for new connections during the sewing trial - regular testing is essential to resolve any sewing errors like short-circuits. We, therefore looked for objects that are easier to remove and support multiple testing during the development. In one iteration, we used a water bottle to stretch the socks (refer Figure 7b); However, the bottle deformed the sock shape and resulted in dislocation of the sensors from the target location.

Later, we utilized a foot mannequin (refer Figure 7c), as it provides a good estimation of the location and supported easy sewing. While the mannequin offered a good solution to design for different foot length, it was not sufficient to develop socks for different foot width. The connections were prone to break when people with different foot structure tried the socks. On investigating deeper as well as learning from previous work [36], we realized that horizontal yarn of a sock makes it stretchable, and all the horizontal connections that we created to sew the electronics made the socks less stretchable and caused breakage issue. Hence, in later iterations, we created all the horizontal connections, particularly near the Arduino board, over a piece of cloth and not directly on the socks (refer Figure 6); Whereas all vertical connections were made with the conductive thread on the socks. Additionally, some extra thread was left in each horizontal connection to accommodate different foot structures, which was hidden underneath the external cloth. Designers could also consider creating a pouch type structure to create better fitting of the socks around the affected foot, as shown in Figure 8. Socks can have different threads (like shoelaces) that are tightened or loosened across different areas as per the patient's condition. This will help in achieving the right fitting of the socks, which is required for accurate monitoring.

4.3 Identify possible variations between textbook knowledge and clinical practice

While designing *SoPhy*, we also found a mismatch in the knowledge between the physiotherapy students and physiotherapists practicing at the hospital. Due to the limited availability of physiotherapists at the collaborating hospital, we first evaluated the design of *SoPhy* in the lab with postgraduate physiotherapy students. For the lab evaluation, the *SoPhy* web-interface presented range of foot movements as numerical values between 0 to 10 (refer Figure 9b). This visualization was designed along with the collaborating physiotherapist, where the numerical values represented the displacement of foot in four directions - upward, downward and sideways. However, the physiotherapy students in the lab study found the numerical values confusing because they described measuring the foot range as an angular displacement. They described

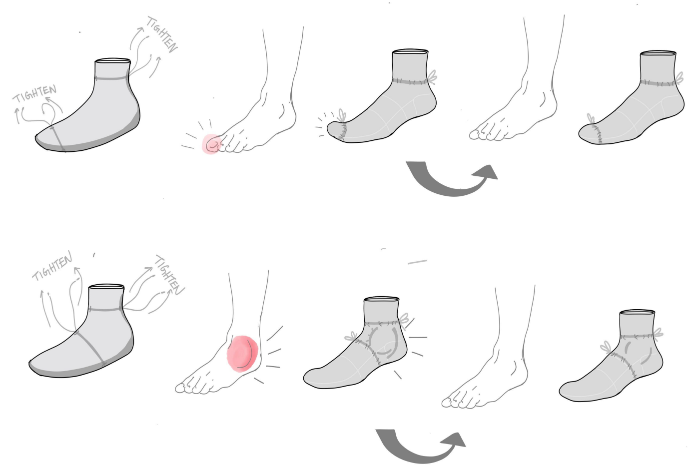

Figure 8: Pouch design for socks to accommodate changing foot condition. Socks can have different threads that are tightened or loosened as per the patient's needs.

Figure 9: Design of the SoPhy system used in the lab study.

foot range as a critical information that they regularly measure using a tool called Goniometer to assess the patient's recovery.

After the lab evaluation, we discussed the findings of the laboratory study with the collaborating physiotherapist and found the difference in the real practice. The physiotherapist described that Goniometer is although a useful assessment tool, it is less meaningful than direct observations of the patient's movements. With experience, observation skills of the physiotherapists improve and then observations become more reliable, as they can observe both the unconscious movements of patients like standing from a chair or walking in the room, and the specific conscious exercises like squats or tip toes. Hence, presenting the range of movement values either as numbers or angular displacement was fine for him because he would mainly refer to the difference in the values. Following the discussion, we revised the web-interface in the second phase and changed the presentation of range of movement with the commonly known measurement, i.e., angular displacement, so that the visualization remains clear to physiotherapists irrespective of their experience (refer Figure 2b for the revised design). It is therefore important to identify such differences in the practice in order to find the best way ahead. Collaborating with clinicians from the beginning of the development is the key to understand the differences.

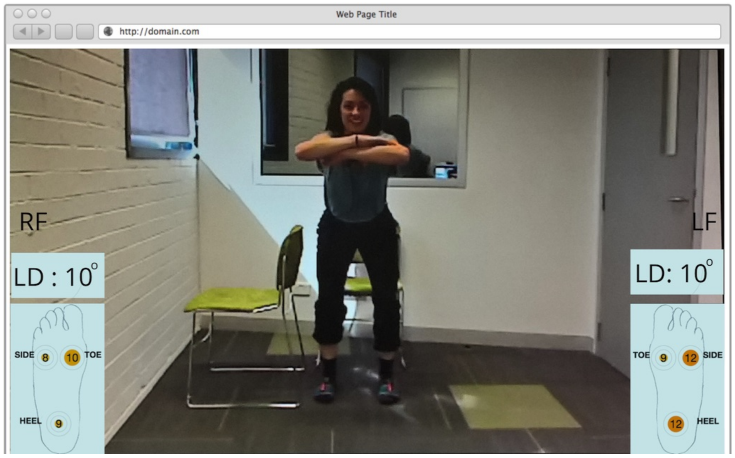

Figure 10: A visualisation sketch with movement data of each foot separately presented on the video stream. This option was discarded in the design phase as it did not support easy comparison between both feet.

4.4 Support comparison-based reflection on sensor data

Domains like Physiotherapy are largely driven by clinician's subjective assessment, where factors like patient observations, verbal confirmation from the patients, and their prior experience - all help clinicians in formulating their assessment. Technological advancements are however, bringing a shift in their clinical practice by providing objective data about patient's physiological signals like movements or heart rate data [28]. Since the objective data like numbers and graphs are not easy to interpret, designers should provide comparison-based reflection on the sensor data.

The collaborating physiotherapist guided us to design a comparison-based interface for *SoPhy* to better support their practice. He described that physiotherapists understand the patient's recovery by comparing the movements of the affected foot with the good foot. He emphasized that the visualisation for both feet should be placed together to compare the sensor values, as the absolute values of these sensors does not hold any meaning. Rather it is the comparison of the values that would highlight the difference in the patient's foot movements. Keeping both the feet together ruled out some options for presenting data that we initially considered. For example, taking inspiration from prior works [5, 23], we also thought to split the visualisation for both feet and render it directly on the video stream, as shown in Figure 10. However, we dismissed this idea as it did not support easy comparison of both feet. Hence, we presented visualisation of the weight distribution and range of movements on separate pair of foot sketches (refer Figure 2b for the final design of the *SoPhy* web-interface). For instance, for weight distribution, the sketch of the feet from underneath clearly presented the distribution of weight on each foot, and having both feet together helped the clinicians to understand the patient's recovery through comparison. Similarly, to present data related to range of foot movements, we used foot sketches with a side view as this arrangement allowed easy comparison of the range values for both feet.

4.5 Embrace the constraints of smart clothing

Strong and colleagues [34] argued that all affordances come with some constraints. In our case, while smart clothing provided the affordance of continuous monitoring for a dynamic setup like physiotherapy session, it also offered certain constraints of hiding the patient's affected body part (feet). The lab study highlighted that the sock interfered in the visual assessment that physiotherapists conducted through the video stream (Figure 9a shows the SoPhy socks used in the lab study). They found it challenging to observe the movements of the patient's foot and toes from within the socks. Such movements help physiotherapists to understand the patient's recovery, their pain level and the efforts required to perform the movement. We designed *SoPhy* socks because being conformed to the body, socks can precisely capture subtleties of lower body movements that are otherwise challenging to observe in a video consultation [1]. While a sock system would always limit the visual assessment to some extent, we found that the problem was aggravated by two other factors: Firstly, the socks used for the lab study were loose fitting, which concealed the foot contours of the patients. Secondly, the socks were grey in colour, which merged with the carpet colour. In the second phase of the development, we revised the design of the socks to overcome these issues. For instance, to reveal the contours of the foot through *SoPhy* socks, we chose stretchable socks made of cotton material. We also thought of using a stretch fabric like spandex to make the foot contours visible; however, we did not use such material as body-fitting material may cause discomfort for patients with a swollen or sensitive foot. Additionally, we also developed two sizes - medium and large, to achieve proper fitting with the socks in the field deployments. Finally, we utilised bright colours such as blue and pink to increase the visibility of the *SoPhy* socks over video.

No matter what measures are taken, smart clothing will hide the concerned body part partially or completely. However, owing to the possibilities smart clothing offers in sensing physiological data, it is important to acknowledge the constraints and find ways to support the required task. Knowing the limitations of the *SoPhy*

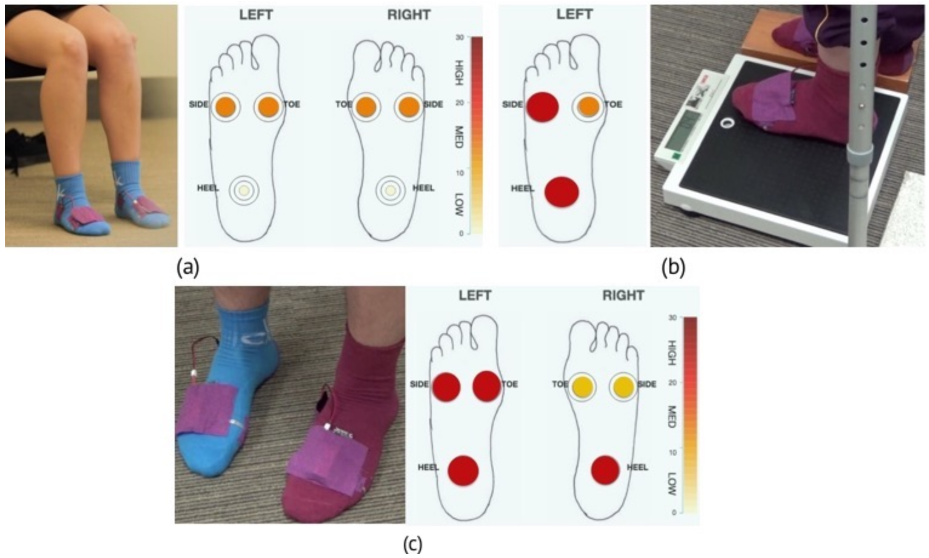

Figure 11: In the field study, the collaborating physiotherapist (Phil) found different use of SoPhy with different patients depending upon their condition. (a) With patient A, SoPhy was used for the entire consultation. Phil used SoPhy to highlight the differences in her weight distribution pattern while sitting and motivated her to try distributing equal weight throughout the foot (b) With patient B, SoPhy was used specifically for one activity in the entire session. Phil used SoPhy along with a weighing scale to better understand her weight bearing patterns on her affected foot while standing. (c) With patient C, SoPhy was used only for a couple of minutes. Phil used SoPhy to highlight how much weight C should be bearing on her affected foot. Because of her irritable condition, she was suggested to only fill yellow colour on the balls of her right foot.

socks in the field study, the physiotherapist used the sock either for a part of the consultation or for the full session depending upon the patient's condition and the therapy goals. The physiotherapist asked the patients to remove the socks when he wanted to assess the patient's condition, e.g., swelling or redness in the affected foot. Figure 11 shows different use cases of *SoPhy* from the field deployments at the hospital [3].

4.6 Integrate and design to match hospital practice

Blandford and others [9–11, 18] have extensively discussed the challenges of working in a health setting that can potentially delay the process of field evaluation and describe some strategies to manage it from the beginning of the project. Following these works, we also tried to integrate the hospital practice in the design of *SoPhy* to make field evaluation of the system feasible in the later phase. Consequently, we closely worked with the collaborating physiotherapist to understand both the hospital and clinician's practise. For instance, clinicians at the collaborating hospital use two screens during video consultations – one for the video stream, and another to check the patient's medical records. Following the suggestion of the collaborating physiotherapist, we presented the *SoPhy* visualisation on a separate screen so that it does not affect the video stream of the patient. The collaborating physiotherapist described that the video stream is his main source of assessing the patients. Presenting the visualisation and video stream together on the same screen would clutter the patient's video stream and would have influenced the physiotherapist's visual assessment. Additionally, augmenting the video stream with the data visualisation would have also raised the issue of data privacy. For instance, the video conferencing tools used at the hospital follow encrypted and secured data communication to ensure privacy of the patient, which was challenging to achieve with a research prototype.

Not only the prototype, we also designed the study protocol around the hospital practice and took some decisions that were not directly relevant to the study aims but were required to conduct the study. Firstly, although the study aimed at understanding the use of *SoPhy* in video consultations, we also conducted field deployments of *SoPhy* in face-to-face consultations. This decision was driven by the hospital guideline, where all new devices are first introduced to the patients in the face-to-face setting before using them in video consultations. Giving a short demonstration of *SoPhy* prior to conducting a video consultation was not considered feasible by the hospital staff because the chronic pain patients typically follow a complex psychological and physical condition. Hence, the study was designed such that all the patients first used *SoPhy* in a face-to-face consultation and then in a video consultation. Secondly, the study was simulated across two rooms at the hospital with patients who were coming to the hospital for face-to-face consultations, and not with those patients who live remotely and essentially adopt video consultations. We took this decision because the hospital ethics committee did not allow the research team to go to the patient's home for conducting the study. Also, *SoPhy* socks were not ready for the unsupervised use and required constant technical support. Hence, mailing the socks to the patient's address was also not a feasible option. Even though the study was not conducted at the patient's home, the sessions involved real patients interacting with their physiotherapist over video about an actual medical condition. The sessions progressed naturally and followed the duration of standard video consultations.

4.7 Understand hospital procedures prior to ethics submission

From our prior experience of working in hospital setting in other projects [1, 30] as well as from the existing literature [11, 18], we were aware of the fact that getting hospital ethics clearance for an external project is time and resource intensive. Having the collaborating physiotherapist on board from the start of the design phase however, significantly helped us in this project. He was able to vouch for the utility of the system, which contributed to the device acceptance both by the hospital staff and the patients. Prior to submitting our ethics application, we systematically list the resources that were needed to evaluate *SoPhy* at the hospital, and strategically met (physically or digitally) a representative of the corresponding hospital department to discuss this study. Consequently, we discussed the project and the ethics application with the head of the collaborating department, telehealth coordinator of the hospital, research coordinator of the collaborating department, other physiotherapists at the collaborating department with research background and IT representative.

These discussions not only helped us to understand the potential challenges prior to the submission but also helped us to develop strategies to resolve them. For instance, as patients were required to wear the *SoPhy* socks, we discussed our application with the device committee and the hygiene committee. We realized that hygiene was a significant issue with *SoPhy* as the socks cannot be washed due to the embedded electronics, which raised the issue of causing infections. We managed this challenge by asking patients to wear a thin stocking underneath *SoPhy* socks to dismiss any direct touch with different bodies. We also wiped out the socks (leaving the electronics) with a disinfectant after every use. Besides, we also understood the correct language to talk about a technology focused research project in hospital settings and other internal communication resources such as the correct ethics application template, importance of feedback on ethics application, and the working style of the hospital staff (e.g., timing to contact and preferred mode of communication). For a faster outcome, approval from multiple people was sought in parallel. At the end of this rigorous process, we developed a strong study protocol with clear description of the resources needed from the hospital and pre-approvals from the concerned authorities. Finally, the application was approved by the hospital ethics committee within two weeks.

The wait involved in the ethics approval also brings another challenge that the electronics used in the system get outdated and better options are available in the market. This can bring designers in dilemma whether to update the system with the new electronics. However, the research team needs to remind themselves that the technology will keep on changing continuously. Our aim with testing a technology is not to test a particular electronic component but rather we are testing the whole concept of introducing a technology in the otherwise limited research context. Besides, better speed or accuracy does not change the user experience significantly in healthcare settings, rather it is how the system supports the unmet needs of patients and clinicians.

5 CONCLUSION

In this paper, we reflected on the journey of a smart clothing product from its development to its evaluation in laboratory and in hospital. This journey brought forward seven key lessons that we think could be useful for HCI researchers as well as practitioners interested in developing a successful smart clothing system for hospital use. We highlighted the importance of collaboration and involving a health practitioner right from the early stages of the development. In our work, the physiotherapist brought immense value and knowledge to the project which we could not have obtained otherwise. His support not only helped us to understand the practice of physiotherapy in real world settings, but also helped us to design a smart clothing product that caters to the needs of both the patients with chronic pain and the hospital protocols. Had the socks been uncomfortable to wear or not accommodative of the varying foot structures, none of the patients would have shown interest in trying out a new smart clothing prototype. Similarly, if the physiotherapist did not know the constraints of *SoPhy* beforehand, he would not have engaged with the system in his time and resource critical consultations. Finally, collaborating with a physiotherapist helped us in resolving issues between the textual knowledge and actual practice; designing a system that adheres to the hospital procedures, and getting access to the required resources at the hospital to satisfy all the procedures of the ethics clearance.

Through these lessons, we extend the prior literature on working in hospital settings [9–11, 18]. We describe the significance of collaborating with clinicians to develop technologies for hospital use and provided specific examples on how collaboration could lead to development and evaluation of a research prototype in hospital settings. We believe these lessons will offer valuable knowledge because they emphasize on the crucial factors of creating a usable healthcare technology (e.g., patient's condition, clinician's practice and hospital protocols) [16, 26], and utilize technical challenges only to build narrative around them. With the change in technical components, the narrative of designers may change but the important factors of working in health settings will still remain valid.

ACKNOWLEDGMENTS

We thank Murdoch Children's Research Institute of Royal Children's Hospital, Australia, for supporting this research. This research was supported by the Melbourne International Research Scholarship, Melbourne International Fee Remission Scholarship, and Microsoft SocialNUI top-up scholarship.

REFERENCES

[1] Deepti Aggarwal, Bernd Ploderer, Frank Vetere, Mark Bradford, and Thuong Hoang. 2016. Doctor, Can You See My Squats?: Understanding Bodily Communication in Video Consultations for Physiotherapy. In Proceedings of the 2016 ACM Conference on Designing Interactive Systems (DIS '16). ACM, 1197-1208. DOI: http://dx.doi.org/10.1145/2901790.2901871

[2] Deepti Aggarwal, Weiyi Zhang, Thuong Hoang, Bernd Ploderer, Frank Vetere, and Mark Bradford. 2017. SoPhy: A Wearable Technology for Lower Limb Assessment in Video Consultations of Physiotherapy. In Proceedings of the 2017

CHI Conference on Human Factors in Computing Systems (CHI '17), 3916–3928. https://doi.org/10.1145/3025453.3025489

[3] Deepti Aggarwal, Bernd Ploderer, Thuong Hoang, Frank Vetere, and Mark Bradford. 2020. Physiotherapy Over a Distance: The Use of Wearable Technology for Video Consultations in Hospital Settings. ACM Trans. Comput. Healthcare 1, 4, Article 21 (September 2020), 29 pages.

[4] Maayan Agmon, Cynthia K. Perry, Elizabeth Phelan, George Demiris, and Huong Q. Nguyen. 2011. A pilot study of Wii Fit exergames to improve balance in older adults. Journal of geriatric physical therapy 34, 4: 161–167.

[5] Swamy Ananthanarayan, Miranda Sheh, Alice Chien, Halley Profita, and Katie Siek. 2013. Pt Viz: Towards a Wearable Device for Visualizing Knee Rehabilitation Exercises. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '13), 1247–1250.

[6] Mobolaji Ayoade and Lynne Baillie. 2014. A Novel Knee Rehabilitation System for the Home. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '14), 2521–2530.

[7] Tony Attridge. 2008. Fitness Trainer Essentials: For the Personal Trainer. Pearson Education Australia.

[8] Australian Physiotherapy Association. 2014. Rural and Remote Australia. A survey report, APA, Melbourne. Retrieved from https://www.physiotherapy.asn.au/DocumentsFolder/APAWCM/Advocacy/2014%20Rural%20and%20Remote%20Australia.pdf

[9] Ann Blandford. 2019. HCI for health and wellbeing: Challenges and opportunities. International journal of human-computer studies 131: 41–51.

[10] Ann Blandford. 2018. Lessons from working with researchers and practitioners in healthcare. Interactions, 72-75. DOI: https://doi.org/10.1145/3292023

[11] Ann Blandford, Erik Berndt, Ken Catchpole, Dominic Furniss, Astrid Mayer, Helena Mentis, Aisling Ann O'Kane, Tom Owen, Atish Rajkomar, and Rebecca Randell. 2015. Strategies for conducting situated studies of technology use in hospitals. Cognition, technology & work, 17, 4: 489–502.

[12] A. J. Bongers, Stuart Smith, Victor Donker, Michelle Pickrell, Rebecca Hall, and Stefan Lie. 2014. Interactive Infrastructures: Physical Rehabilitation Modules for Pervasive Healthcare Technology. In Pervasive Health. Springer, London, 229–254.

[13] Gilsoo Cho. 2009. Smart Clothing: Technology and Applications. CRC Press.

[14] Ella Dagan, Elena Márquez Segura, Ferran Altarriba Bertran, Miguel Flores, Robb Mitchell, and Katherine Isbister. 2019. Design Framework for Social Wearables. In Proceedings of the 2019 on Designing Interactive Systems Conference (DIS '19), 1001–1015.

[15] Julie Doyle, Cathy Bailey, Ben Dromey, and Cliodhna Ni Scanaill. 2010. BASE - An interactive technology solution to deliver balance and strength exercises to older adults. In Proceedings of the 4th International ICST Conference on Pervasive Computing Technologies for Healthcare. https://doi.org/10.4108/icst.pervasivehealth2010.8881

[16] Anne G. Ekeland, Alison Bowes, and Signe Flottorp. 2010. Effectiveness of telemedicine: A systematic review of reviews. International Journal of medical informatics 2010, 79(11), 736–771.

[17] Geraldine Fitzpatrick, and Gunnar Ellingsen. 2013. A review of 25 years of CSCW Research in Healthcare: Contributions, Challenges and Future Agendas. Computer Supported Cooperative Work (CSCW), 22, 4-6, 6

[18] Dominic Furniss, Rebecca Randell, Aisling Ann O'Kane, Svetlena Taneva, Helena Mentis, and Ann Blandford. 2014. Fieldwork for Healthcare: Guidance for Investigating Human Factors in Computing Systems. Synthesis Lectures on Assistive, Rehabilitative, and Health-Preserving Technologies 2, 1: 1–146.

[19] F. Gemperle, C. Kasabach, J. Stivoric, M. Bauer, and R. Martin. 1998. Design for wearability. In Digest of Papers. Second International Symposium on Wearable Computers, 116–122.

[20] Trisha Greenhalgh, Joe Wherton, Sara Shaw, and Clare Morrison. 2020. Video consultations for covid-19. BMJ 368: m998.

[21] Linsey Griffin, Crystal Compton, and Lucy E. Dunne. 2016. An analysis of the variability of anatomical body references within ready-to-wear garment sizes. In Proceedings of the 2016 ACM International Symposium on Wearable Computers (ISWC '16). Association for Computing Machinery, New York, NY, USA, 84–91. DOI:https://doi.org/10.1145/2971763.2971800

[22] Jun-Da Huang. 2011. Kinerehab: A Kinect-based System for Physical Rehabilitation: A Pilot Study for Young Adults with Motor Disabilities. In The Proceedings of the 13th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS '11), 319–320.

[23] Agnes W. K. Lam, Danniel Varona-Marin, Yeti Li, Mitchell Fergenbaum, and Dana Kulić. 2016. Automated Rehabilitation System: Movement Measurement and Feedback for Patients and Physiotherapists in the Rehabilitation Clinic. Human–Computer Interaction 31, 3-4: 294–334.

[24] Deborah Lupton. 2020. Digital media and health. In The Sage International Encyclopedia of Mass Media and Society. SAGE Publications, Inc.

[25] Steve Mann. 1996. Smart Clothing: The Shift to Wearable Computing. In Communications of the ACM 39, 23–24.

[26] Sarah Mennicken, Oliver Sack, and Martina Ziefle. 2011. People and a virtual doctor's visit: learning about multiple acceptance aspects of a telemedical scenario. In Proceedings of the 5th International Conference on Pervasive Computing Technologies for Healthcare, PervasiveHealth, 2011, 577-584.

[27] Helena M. Mentis, Ahmed Rahim, and Pierre Theodore. 2016. Crafting the Image in Surgical Telemedicine. In Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing (CSCW '16), 744–755.

[28] Helena M. Mentis, Rita Shewbridge, Sharon Powell, Melissa Armstrong, Paul Fishman, and Lisa Shulman. 2016. Co-Interpreting Movement With Sensors: Assessing Parkinson's Patients' Deep Brain Stimulation Programming. Human–Computer Interaction 31, 3-4: 227–260.

[29] Kenton O'Hara, Cecily Morrison, Abigail Sellen, Nadia Bianchi-Berthouze, and Cathy Craig. 2016. Body tracking in healthcare. Synthesis Lectures on Assistive, Rehabilitative, and Health-Preserving 5, no. 1 (2016): 1- 151.

[30] Bernd Ploderer, Justin Fong, Anusha Withana, Marlena Klaic, Siddharth Nair, Vincent Crocher, Frank Vetere, and Suranga Nanayakkara. 2016. ArmSleeve: A Patient Monitoring System to Support Occupational Therapists in Stroke Rehabilitation. In Proceedings of the 2016 ACM Conference on Designing Interactive Systems (DIS '16), 700–711.

[31] Aneesha Singh, Stefano Piana, Davide Pollarolo, Gualtiero Volpe, Giovanna Varni, Ana Tajadura-Jiménez, Amanda Cdec Williams, Antonio Camurri, and Nadia Bianchi-Berthouze. 2016. Go-with-the-Flow: Tracking, Analysis and Sonification of Movement and Breathing to Build Confidence in Activity Despite Chronic Pain. Human–Computer Interaction 31, 3-4: 335–383.

[32] Duncan Roderick Stevenson. 2011. Tertiary-Level Telehealth: A Media Space Application. Computer Supported Cooperative Work (CSCW), 20: 61-92.

[33] Sheila Rosenberg, Emily Rosario, Julia Yeung, Davis Catolico, Russell Daniel, Ryan Lovell, Niko Fullmer, Elise Pearson, and Ruiqi Tang. 2016. Evaluation of a Wearable "Smart Socks" Gait Monitoring System for Improving Rehabilitation. Archives of physical medicine and rehabilitation 97, 10: e77.

[34] Diane M. Strong, Olga Volkoff, Sharon A. Johnson, Lori R. Pelletier, Bengisu Tulu, Isa Bar-On, John Trudel, and Lawrence Garber. 2014. A Theory of Organization-EHR Affordance Actualization. Journal of the Association for Information Systems 15, 2: 2.

[35] Richard Tang, Xing-Dong Yang, Scott Bateman, Joaquim Jorge, and Anthony Tang. 2015. Physio@Home: Exploring Visual Guidance and Feedback Techniques for Physiotherapy Exercises. In Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems, 4123–4132.

[36] G. Tao, P. S. Archambault, and M. F. Levin. 2013. Evaluation of Kinect skeletal tracking in a virtual reality rehabilitation system for upper limb hemiparesis. In 2013 International Conference on Virtual Rehabilitation (ICVR), 164–165.

[37] Liezl van Dyk. 2014. A review of Telehealth Service Implementation Frameworks. International journal of environmental research and public health 11, no. 2 (2014): 1279-1298.

[38] Clint Zeagler. 2017. Where to wear it: functional, technical, and social considerations in on-body location for wearable technology 20 years of designing for wearability. In Proceedings of the 2017 ACM International Symposium on Wearable Computers (ISWC '17), 150–157.