Physiotherapy Over a Distance: The Use of Wearable Technology for Video Consultations in Hospital Settings

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Wearable technologies offer potential in supporting assessment of lower limb movements in video consultations, which otherwise are challenging to assess. Yet there remains a limited understanding of how such technologies can be used to improve video consultations in a hospital setting and how they contribute to the clinician-patient interactions over a distance. In this article, we report on the findings of the field evaluation of a wearable technology—SoPhy. SoPhy consists of a pair of sensor embedded socks that capture the lower limb movements of a patient and a web-interface to visualise these movements for the remote physiotherapist. Our study demonstrates that SoPhy helped the physiotherapist in identifying the subtle differences in patients’ movements across all six phases of a consultation. SoPhy increased the confidence of the physiotherapist and guided more accurate assessment of the patients. SoPhy visualisation enhanced the overall clinician-patient communication and offered a better understanding of the therapy goals to the patients. Using the characteristics of the visualisations, patients were able to plan specific goals. We discuss how SoPhy helped in addressing challenges in video consultations experienced by a physiotherapist, and beyond that, how it enabled collective reflection between therapist and patient.

CCS Concepts: • Human-centered computing → Interaction design; Interaction design process and methods; Human computer interaction (HCI); Field studies;

Additional Key Words and Phrases: Video consultation, Physiotherapy, clinical efficacy, video conferencing, wearable technology

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1 INTRODUCTION

With the emergence of small, low-cost sensors, there has been significant interest in wearable rehabilitation systems that generate objective information about patient movements [O’Hara et al. 2016; Aggarwal et al. 2017; Ploderer et al. 2016; Ananthanarayan et al. 2013]. Movement sensing systems can be attached to the body (such as head-mounted webcams), are portable (such as smartphones), can be worn on or under clothes (such as bands), or may even become clothes themselves (such as socks). Sensors, such as implantables [Mann 1996] or insertables [Heffernan et al. 2016], can also be placed inside the body. Being attached to the body, these sensing systems can detect accurate information about a patient.

Information about bodily movement is particularly relevant to the practice of Physiotherapy. Physiotherapy is helpful in the physical rehabilitation of the patients, where the goal is to restore and regain physical strength and functioning of the affected body part through manipulations and exercises. To assess the patient’s recovery, physiotherapists observe the fine details of the patient’s bodily movements. For lower limb conditions, the details include distribution of bodily weight across the feet, and range of movement in the limbs and joints. These details are easily observed when patient and physiotherapist are collocated, as the physiotherapist can easily move around the patient to appraise the movements. However, understanding the specifics of patients’ body movements becomes challenging in video consultations as the physiotherapist can only see the patient on a two-dimensional screen [Aggarwal et al. 2016]. The flattening of spatial information into two dimensions makes it difficult to assess movements, because our spatial understanding relies on being able to relate body movements and tasks accurately to the environment [Presson and Montello 1994].

In clinical settings, these challenges directly influence the assessment and treatment of the patient’s condition [Aggarwal et al. 2016; Mentis et al. 2016; Stevenson 2011]. A consultation may yield effective outcomes if the clinician is able to confidently assess the patient and can accordingly suggest a suitable treatment [Demiris et al. 2010; Fryback and Thornbury 1991; Kim 2013; Stewart 1995]. While there have been several attempts in designing wearable technologies for rehabilitation [Aggarwal et al. 2017; Ananthanarayan et al. 2013; Ayoade and Baillie 2014; Hoang et al. 2016; Lam et al. 2016; Ploderer et al. 2016; Singh et al. 2016], these works are limited to laboratory settings, or are focused on supporting patients at home, or are designed for face-to-face consultations. To the best of our understanding, there has not been any field evaluation of a new wearable technology in naturally occurring video consultations of physiotherapy that aims to support the needs of physiotherapists.

This article investigates the use of a bespoke wearable technology, SoPhy [Aggarwal et al. 2017] to support physiotherapists in assessing and treating lower limb movements in video consultations. SoPhy monitors and presents data related to three key aspects of lower limb movements—weight distribution, range of movement and foot orientation. SoPhy consists of a pair of sensing socks that captures the patient’s lower body movements, and a web-interface that presents the captured information to the remote physiotherapist in real time. Building on initial findings from our lab study [Aggarwal et al. 2017], we conducted a field evaluation of SoPhy at a large pediatric hospital, where the device was used by a physiotherapist and three patients for five months. Moving from the lab into a hospital allowed us to gain insights about how SoPhy is integrated in the dynamics of real-world video consultations, i.e., how physiotherapists use SoPhy for the specific needs of various patients, how it might influence the physiotherapist’s decision making, and how it might influence clinician-patient communication over a distance.
We report on six naturally occurring video and face-to-face consultations, where SoPhy was used by a physiotherapist and three patients with lower limb issues. Video consultation for physiotherapy is not yet recognized as legitimate standalone clinical practice. Therefore, the SoPhy video consultations are organized in combination with face-to-face consultations. Hence, we evaluated SoPhy in both face-to-face and video consultations. We demonstrate that lower limb issues can be effectively assessed and treated over video by designing technologies that mediate bodily information. We provide evidence of this argument through an analysis of six phases of a clinical consultation [Byrne and Long 1976] and explain how the availability of key bodily cues guides the physiotherapists in their clinical tasks throughout a consultation. This is a novel contribution, because there have been only a few field studies of new prototype systems in hospital setting, as also noted by Blandford [2018] and Fitzpatrick and Ellingsen [2013]. Additionally, we demonstrate how the use of SoPhy resolved the challenges related to mediating crucial lower limb movement data in physiotherapy video consultations [Aggarwal et al. 2016]. Sensor data proved helpful for both the physiotherapist and patients across six phases of a consultation. Based on our findings, we highlight future directions for designing movement visualisations and supporting collective reflection and recovery.

2 RELATED WORK

There has been a growing interest in video consultations over the past decade [Demiris et al. 2010; Ekeland et al. 2010; Fitzpatrick and Ellingsen 2013; Miller 2011]. Several works have explored the feasibility of video consultations for various clinical domains, such as surgery [Mentis et al. 2016; Stevenson 2011], dermatology [Larsan and Bradram 2008], autism-related parent training [Aggarwal et al. 2015], and physiotherapy [Aggarwal et al. 2016]. Video consultations are typically facilitated by video conferencing tools like Skype. The state-of-the-art video conferencing tools support the five aspects that are essential for supporting communication over a distance, as suggested by Olson and Olson [2000]: visibility (visible to each other), audibility (speech), contemporality (real-time message delivery), simultaneity (both ends can send and receive information), and sequentiality (turn-taking). These five features of remote communication are sufficient for tasks that mainly require verbal communication between remote callers such as official meetings or personal communication. However, they are not sufficient in a clinical setting, because clinical interactions go beyond talking heads and involve bodily interactions between patients and clinicians. Several works therefore highlight the challenges of video technology in supporting effective assessment and treatment of the patients over a distance [Aggarwal et al. 2016; Larsan and Bradram 2008; Miller 2011].

Our previous work [Aggarwal et al. 2016] highlighted the challenges faced by the physiotherapists in assessing and treating patients in video consultations. The authors conducted an observational study to understand the standard video consultations practice at a children’s hospital, where the video consultations were undertaken using tools like GoToMeeting1 and HealthDirect.2 We utilised the six phases of a clinical consultation [Byrne and Long 1976] to illustrate the difficulties that the physiotherapists faced at different times of a consultation. These six phases of video consultations are structured around the needs of the clinicians and describe the activities that unfold between patients and clinicians at different times of a consultation. Below, we illustrate the challenges of physiotherapists for all six phases (Refer to Table 2 for a summary of the challenges).

1 GoToMeeting: https://www.gotomeeting.com/en-au.
2 HealthDirect: https://www.healthdirect.gov.au/.
conversations indirectly provide details on patient’s everyday routine and their pain experiences. Finally, there are limited opportunities to involve other clinicians in video consultations, because clinicians find it difficult to manage turn-taking and to initiate group-like experience over video. This, in turn, reduces the ability of the clinicians team to formulate a collective assessment—an aspect essential for treating patients with chronic pain conditions. As a result, face-to-face consultations are scheduled to understand the patient’s condition.

2. History Taking—In this phase, patients describe their recovery from the last consultation [Byrne and Long 1976], e.g., patients perform different exercises to demonstrate their recovery. When the patients perform exercises, physiotherapists want to observe subtle differences in their movements, e.g., depth of squats, fatigue, range of arm movements, and weight distribution over foot [Aggarwal et al. 2016]. However, these fine details are challenging to observe over video, and physiotherapists have to be reliant on the verbal explanation of the patients to understand their recovery. However, patients also struggle to get higher mobility with the underlying technology. These attempts raise concerns at the patient end, where they feel uncomfortable in performing certain types of exercises over video, e.g., performing shoulder rolls while lying down on the bed.

3. Examination—This phase is dedicated for the clinician to conduct a verbal or physical examination of the patient to understand the underlying health issue [Byrne and Long 1976]. Since physical examination is not possible to conduct over video, physiotherapists miss out the necessary tactile information related to the patient’s body (e.g., inflammation and increased body temperature) and their response to touch [Aggarwal et al. 2016]. Additionally, conducting covert assessment of the patients with the surroundings is also challenging over video, as physiotherapists have limited field-of-view of patient’s side and have limited opportunities for informal conversation. Lack of bodily cues reduces the confidence of the physiotherapists in their assessment, and they often organise a follow-up face-to-face consultation to better understand the patient’s condition. Confidence in diagnosis is defined as a major factor contributing to the efficacy of a clinical consultation [Fryback and Thornbury 1991; Stewart 1995]. Earlier studies illustrate the consequences of the reduced diagnostic confidence of clinicians during video consultations. For instance, clinicians demonstrated limited ability in making decisions over video [Lee et al. 2015], and more pathology tests were suggested to get a better understanding of the patient’s health issue [Bulik 2008].

4. Diagnosis—Based on the performed examination, the clinician then describes the underlying issue to the patient by using the established medical information [Byrne and Long 1976]. Generally, video consultations are follow-up sessions with the existing patients and does not involve any fresh medical diagnosis, as was also seen in our previous study [Aggarwal et al. 2016]. This phase is, therefore, absent in video consultations.

5. Treatment—In this phase, the clinician suggests a medication or therapy to the patient to help them recover [Byrne and Long 1976]. In video consultations, since physiotherapists have limited understanding of the patient’s condition from the beginning, they were reluctant to try new exercises with patients [Aggarwal et al. 2016]. Reduced confidence in assessment influenced the treatment process of physiotherapists. They mainly tweak the previously suggested exercises and at times when they need to change the therapy plan, they prefer to schedule the next appointment as face-to-face session to go through the new exercises.

6. Closing—Finally, the clinician concludes the consultation through informal conversations and schedules another appointment, if required [Byrne and Long 1976]. Unlike face-to-face consultations, this phase is very brief in video consultations [Aggarwal et al. 2016]. Patients remain seated in front of the webcam until the end of the session. Consequently, physiotherapists cannot observe their body language and posture that demonstrate their satisfaction with the session. Moreover, video consultations follow a different procedure than face-to-face sessions, where the goodbye means switching off the video call directly. Hence, physiotherapists are again reliant on the verbal confirmation of the patients to understand any outstanding issues.

In summary, the visibility of information [Olson and Olson 2000] during video consultation is a major concern. This arises because a range of bodily cues (e.g., weight distribution, range of movement and muscle tightness) are not mediated by the video technology across all phases. The absence of these bodily cues limits the assessment and treatment processes of physiotherapists. Moreover, lower limbs are not visible in video as the camera
remains focussed on the upper torso—due to which physiotherapists found it challenging to assess lower limb movements in video consultations. Focusing the camera to the specific body parts limits other crucial information related to patient’s full body posture, and facial expressions that clinicians observe to understand the patient’s recovery. Limited availability of the essential bodily cues of the patient’s movements reduced the physiotherapists’ confidence in their assessment and influenced their treatment outcome in video consultations [Aggarwal et al. 2016].

Previous works suggest that a consultation may yield effective outcomes if the clinicians are confident on their diagnosis and are able to suggest a treatment that works for the patients [Demiris et al. 2010; Fryback and Thornbury 1991; Kim 2013; Stewart 1995]. Demiris et al. [2010] emphasized that to make a video consultation effective, it is essential to equip the patient and clinician with the right technology such that the patients are able to describe their symptoms and clinicians can perform the necessary assessment and treatment. Fryback and Thornbury [1991] also emphasized on the challenge of evaluating the influence of a new system on the patient’s health, as the health outcomes follow a long-term trajectory. Hence, they suggested to investigate the impact of the system on the decision-making abilities of the clinicians. They noted that a system is helpful if it “changes the differential diagnosis, strengthen an existing hypothesis or simply reassure the clinician” [Fryback and Thornbury 1991, p. 91].

Other researchers have explored the use of interactive technologies to make video consultations effective. For example, Mentis et al. [2016] 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 [2011] used multiple webcams and a pen-and-tablet system to support rich interactions in surgery related video consultations. They described that the pen-and-tablet system helped in mediating gestures around the patient’s records and provided patients with a better understanding of their symptoms and treatment. However, multiple webcams supported rich bodily information related to body orientation, eye gaze and attention space of the participants. These works present important insights on the potential of interactive technologies in enhancing the decision-making abilities of clinicians in video consultations and inspired us to develop suitable technology for supporting the needs of physiotherapists in video consultations. Next, we review the existing technologies for physical rehabilitation.

2.1 Technologies for Physical Rehabilitation

Within HCI, there is a significant interest on supporting physical rehabilitation of patients. A majority of these investigations aim to support patients at home during the rehabilitation program or post-program to help them in maintaining their active routine in the absence of guidance from physiotherapists [Agmon et al. 2011; Bongers et al. 2014; Doyle et al. 2010; Esculier et al. 2012; Tang et al. 2015; Singh et al. 2016]. While some technologies provide ways to connect patients and physiotherapists remotely [Ayoade and Baillie 2014; Doyle et al. 2010; Lam et al. 2016], none of them is explicitly designed or evaluated to support clinician-patient interactions in video consultations of physiotherapy. O’Hara and colleagues presented a review of the sensing technologies that have been explored to support rehabilitation [O’Hara et al. 2016]. They described that the sensing systems vary in their shapes and application areas, with some designed to be body-worn for continuous monitoring of the patient’s movements, whereas others are embedded in the immediate surroundings to support non-intrusive tracking of patient’s movements. We have utilised the authors’ description to discuss the existing technologies for physical rehabilitation. Below, we will review the existing body-sensing technologies across two categories: Environmental tracking and on-body tracking. Since there is a significant number of technological solutions for tracking bodily data (like range of knee angle and balance), we will only review those works that monitor and provide feedback about bodily data. In this regard, systems that are mainly designed to make the rehabilitation process engaging through gamification and score boards, for example, are not discussed.
2.1.1 Environmental Tracking. Environmental tracking includes monitoring of the patient’s movements using systems that are arranged in the surroundings. Technologies following environmental tracking typically work with automated pose detection and estimation techniques using computer vision approaches [O’Hara et al. 2016]. Commercially available technologies like Playstions camera, Microsoft Kinect and Wii-Fit Board have been commonly utilised to explore the potential of tracking patient’s movements for rehabilitation purposes. 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. Some studies [Agmon et al. 2011; Esculier et al. 2012] highlight that the balance board is safe to be used by the patients at home under limited supervision and that it improved the balance of the patients. Since Wii-Fit balance board provide limited surface area for exercises, other researchers [Bongers et al. 2014] have also looked into pressure sensitive surfaces to support dynamic exercises (e.g., jumping and walking). The authors studied the use of their system with the patients at home and described that the interactive surfaces increased the motivation of the patients to be active.

Along the similar lines, Physio@Home [Tang et al. 2015] is a system that is designed to support arm and shoulder rehabilitation of patients at home. The system utilises multiple Vicon motion tracking cameras to capture information related to range of arm movement, joint positions and angles, extent of movement and rate of movement. 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. Similarly, OneBody [Hoang et al. 2016] is another system that utilises Microsoft Kinect and Oculus virtual reality headsets to support posture guidance between an instructor and a student over a distance. In this system, Kinect performs skeletal tracking at both ends and creates virtual avatars in real time. These virtual avatars are superimposed in the virtual reality environment and are presented to the instructor and student through head mounted display from first person perspective. Through a laboratory study with healthy participants, the authors described that the superimposed view of the instructor and student bodies supported more effective bodily communication than what is possible in video conferencing through verbal communication.

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 and cannot support more dynamic movements like walking. However, the depth sensors of Kinect are capable of capturing the coarse-grained movements but have limitations in accurately capturing the fine-grained movements, particularly, related to lower limb [Huang 2011; O’Hara et al. 2016; Tao et al. 2013]. Hence, researchers explored the use of sensors to sense movements by attaching sensors on the body, which we discuss next.

2.1.2 On-body Tracking. On-body tracking systems (or Wearables) are the systems that track the movements through sensing units attached on the body. One common form for these systems include bands that patients can fasten to monitor movements of their affected parts. For instance, ArmSleeve [Ploderer et al. 2016] is a 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. Occupational therapists used this system during the face-to-face visits of the patients at the hospital. The system captures information related to range of movement of three joints, number of movements, time spent exercising, common postures of the arm and quality of movements on a scale of 1 to 10. The sensing unit consists of three bands that patients in three joints: wrist, elbow, and arm and shoulder joint. The evaluation highlighted that the therapists appreciated the presented information on the dashboard, however, they found it challenging to understand the context of the patient’s movements (i.e., intention and purpose of the movement) through the presented data. Their reported challenge speaks to the typical challenge with the sensor data, as making sense of the continuous stream of the sensor data is always challenging [Mentis et al. 2015; Morrison et al. 2016].

Along the similar lines, band shaped wearables are also developed to accurately capture knee movements [Ananthnarayan et al. 2013; Ayoade and Baillie 2014; Lam et al. 2016]. For instance, Rehabilitation Visualisation
System (RVS) provides real-time feedback related to patients about the range of motion of knees [Ayoade and Bailie 2014]. The angle is captured using two IMU sensors. The captured data is presented on a screen where the angle is shown using a graphical fan with changing color gradient. The authors evaluated the system with knee replacement patients at home for six weeks and described that the patients using the system recovered better than the patients in the control group. The system also allows the physiotherapist to check the patient’s progress remotely. However, details of how a physiotherapist will use the system are not provided. The authors briefly mention a possible communication between a patient and physiotherapist through video calling to illustrate that remote communication is possible with the developed system. However, details of what information a remote physiotherapist will and how they will use the system over a distance are not discussed.

PT Viz [Ananthanarayan et al. 2013] also detects the bend angle of knee, but it provides the visual feedback directly on the wearable. The system consists of two enclosures one for thigh and another for calf. The knee angle is detected using a bend sensor, and the visual feedback is provided on a set of five bars attached on the thigh enclosure. These lines light up according to the degree of patient’s movements, e.g., for full knee bend, all lines will lit. The system was used as a probe to understand the needs of patients undergoing knee rehabilitation in a usability study conducted in the lab. The study highlighted that the abstract visualisation was appreciated by patients, as it motivated them to try harder and provided embodied feedback on the movements. They described that the system was more suitable for the patients recovering from surgery than the patients having chronic conditions, because the system could not provide feedback on the subtle differences in the movements that are more essential for the chronic pain patients.

Automated Rehabilitation System (ARS) is another system designed for physiotherapists to monitor the recovery of patients with knee and hip replacement in the clinic [Lam et al. 2016]. ARS consists of a sensing bands with inertial measurement units that monitors the patient’s posture and presents visual feedback on their movement. System also provides a novel exercise guidance feature to support patients while exercising. The visual feedback is graphically represented as an animation overlaid on the instructed motion visuals of the exercise. The authors followed an iterative design process and developed the system in collaboration with physiotherapists and patients. With ARS, physiotherapists can quantitatively measure patient movements, assess their recovery, and manage and schedule exercise regimens for patients. Their field study illustrated that visual feedback guided better performance of exercises in patients.

Go-with-the-flow is another system designed in collaboration with clinicians to improve the quality of life of patients having chronic lower back pain [Singh et al. 2016]. The system consists of a smartphone and two respiration sensors, each attached on a band that the patient can wear to monitor the movements. The band with smartphone is attached on the trunk of the patient and the bands with respiration sensors are fastened on the chest. While the sensors of the smartphone capture information of the patient’s trunk movements, respiration sensors sense the breathing patterns. Based on the movements, the system generates audio feedback using different types of sounds, such as sound of moving water, wind-chimes and waves. Through lab and field studies, the authors suggest that audio feedback increased the patient’s performance, motivation and awareness of movements, while keeping them relaxed during exercising.

Auditory feedback was also explored by Newbold et al. [2016] to improve self-efficacy of the chronic pain patients in doing movements. The authors used Western music tones to demonstrate that the use of musical structures can both encourage movements and avoid overdoing on it. In a similar vein, Tajadura-Jiménez et al. [2015] investigated the use of a sensing gait system to understand the effect of sound feedback on one’s walking patterns. They found that manipulating the sound feedback of one’s footsteps lead to change in the individual’s gait patterns. They reported that people felt lighter/thinner and demonstrated more energy in walking on hearing high frequencies of their footstep sound. These findings have implications for chronic pain patients particularly for those who have altered perceptions of their affected body part.

BASE [Doyle et al. 2010] is another system that is designed to improve lower limb strength and balance of elderly people. The system supports elderly people at home by delivering them a personalised,
physiotherapist-prescribed exercise program. In this regard, the system includes a “Physio Console” that allows the physiotherapist to remotely observe and modify the exercise routine. The system provides video instructions for a variety of exercises and provides both visual and audio feedback to users in real time. The sensing unit is a band consisting of two SHIMMER kinematic sensors that patients wear near the ankles. Correctness of exercises are measured by tracking the movements through a webcam. However, the article does not provide details of how the balance and strength data are visualised on the screen, and how can a physiotherapist use the “Physio Console” to set the exercise routine.

Finally, sensing socks [Najafi et al. 2013] and shoes [Sarnow et al. 1994] are also developed to help people in improving their postural stability in everyday routine. As an example, Sensoria Fitness socks\(^3\) and shoes are commercially available wearables that have sensors embedded inside the sock material and in-shoe soles, respectively. These sensors capture information related to the walking and running pattern of the person, 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, e.g., the foot landing pattern is visualised using colors on the foot sketches showing the foot from underneath. The app also shows a summary of the activity to describe the overall pattern that the user followed in doing the activity, e.g., the percentage of the correct landing pattern while walking or running. Although these wearables 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 [Rosenberg et al. 2016]. Hence, the socks can be utilised by the patients outside the clinic for monitoring their gait patterns.

While the existing systems demonstrate the significant potential of wearable technologies to support physical rehabilitation for patients, none of these systems are specifically designed for video consultations. Additionally, majority of the existing systems aim to support patients for home-based rehabilitation in the absence of the physiotherapist. There has been limited attempts to provide support for the physiotherapist in their assessment and treatment procedures, except for the work by Lam et al. [2016]. Finally, 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 [Aggarwal et al. 2016]. 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. These subtle differences are difficult to mediate with current video conferencing tools, because these tools are typically configured to support talking heads conversations and have little consideration for the observation of full body movements [Heath and Luff 1992].

This article, therefore, extends the existing research by investigating the use of a wearable technology that:

- is integrated into the video consultation between a patient and physiotherapist,
- has active real-time contribution by physiotherapists,
- provides accurate information for diagnosis and assessment of body movements,
- focuses on lower limb rehabilitation.

The bespoke system, SoPhy, supports the needs of physiotherapists in assessing and treating patients with lower limb issues in video consultations. We evaluated the system in a pediatric hospital, where it was used by a physiotherapist and three patients for five months. Before describing the study design, we first describe the design of the SoPhy system.

\(^3\)Sensoria socks: http://www.sensoriafitness.com/.
3 SOPHY DESIGN AND LAB EVALUATION

SoPhy [Aggarwal et al. 2017] is a wearable technology that captures key aspects of the lower limb movements and communicates the information to the physiotherapists in video consultations (refer Figure 1). SoPhy has two parts: (1) a pair of socks that captures details of the patient’s movements, and (2) a web-interface that presents the information related to weight distribution, foot orientation and range of movements to the physiotherapists in real time.

Rationale behind choosing socks over any other form of sensing device like shoes or mats was as follows: First, socks are lightweight and therefore comfortable to wear while exercising. Second, socks conform to the body and move along with the patient; hence, they can precisely capture details of both the static and dynamic movements involved in a physiotherapy session. Finally, sensor-based socks have been successfully used in other clinical domains such as to help manage foot ulcers [Najafi et al. 2013] and to support everyday physical activity (e.g., Sensoria socks), which further inspired the use of socks. More details of the design process and rationale behind design choices are available in Aggarwal et al. [2017].

During a video consultation, when the patient wears the SoPhy socks and performs lower body exercises (such as squats and tiptoes), the physiotherapist sees the details of the movements on the SoPhy web-interface. SoPhy captures and presents the following three types of information:

- **Weight distribution** describes the amount of weight a person is bearing on the feet. SoPhy captures the weight-bearing patterns through the three pressure sensors sewed on the socks at the balls and heel of the foot (see Figure 1(a)). On the web-interface, this data is visualised on a continuous color spectrum from light yellow to dark red (see Figure 1(b)). Each sensor point consists of three concentric circles, where the circles represent a specific category of weight distribution: Low (0–9), Medium (10–19), and High (20–30).

- **Foot orientation** refers to the foot alignment across four directions: upward, downward, inside, and outside of the foot. Physiotherapists understand the sideways foot orientations through weight-bearing patterns [Aggarwal et al. 2017]. Hence, the information is inferred from the weight distribution visualisation. Whereas the movement in upward and downward directions are assessed through angular displacement of the foot—the information is presented by the range of movement visualisation.

- **Range of movement** refers to the angular displacement of the foot from the ankle joint, in the upward and downward directions. The angle is calculated by an IMU sensor attached on the bridge of the foot (see Figure 1(a)). This data is visualised through foot sketches using a wedge visualisation (refer Figure 1(b)). These foot sketches move up and down in between the maximum degrees defined for a healthy person, i.e., 30 degrees upwards and 50 degrees downwards [Attridge 2008].
This article builds upon our prior work [Aggarwal et al. 2017], where we evaluated SoPhy in a controlled lab environment with surrogate patients and student physiotherapists. The study demonstrated that: (i) participants were more confident in assessing the patient’s lower limb movements with the SoPhy system as compared to the standard video consultations; (ii) participants required fewer repetitions of exercises to understand the patient’s condition with SoPhy; (iii) information related to weight distribution was valued the most; and (iv) use of SoPhy differed for different pain intensity, with the system being an assessment tool for low pain and a training tool for high pain levels. This study extends our prior work by undertaking research in situ in a hospital, with actual physiotherapists and real patients who are experiencing complex health issues. We investigate the use of SoPhy across six different phases in a consultation (Byrne and Long, 1976) (as discussed in the previous section). Next, we describe the design of the field study.

4 FIELD STUDY OF SOPHY

The aim of this study is to understand how SoPhy helps physiotherapists assess and treat lower limb movements in video consultations. We conducted field deployments of SoPhy in six naturally occurring video and face-to-face consultations for physiotherapy at a large pediatric hospital. The study was conducted through the hospital’s Pain Management clinic. This clinic offers service to patients having chronic pain issues and organizes regular video consultations to help them manage their long-term condition. The study was approved by the hospital ethics committee.

4.1 Study Design

The design of the field study was informed by the sensitivity of the clinical setting and the hospital ethics guidelines. Several decisions were taken that deflected from the study aims but were essential to conduct this study. First, the study was conducted with patients who were coming to the hospital for face-to-face consultations and not with those patients who essentially adopt video consultations. This decision was inspired by the fact that patients who are typically involved in video consultations live in rural areas and getting access to them was challenging due to hospital ethics guidelines. Additionally, the socks were not ready for the unsupervised use and required constant technical support. Hence, mailing the SoPhy socks to the patient’s address was also not appropriate. Consequently, we simulated the setting of video consultations across two rooms (on different floors) at the hospital. 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.

Moreover, 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 follow a complex psychological and physical condition. Hence, the study was designed such that all the patients used SoPhy first in a face-to-face consultation and then in a video consultation (refer Figure 2). The study design involved observations of at least two sessions with each physiotherapist-patient pair. All subsequent sessions were required to follow the structure of the second session. However, we could not follow this study design with all the patients due to their health condition, which we will discuss in the next section.

Session 1: Face-to-face Consultation (60 min). The first session aimed to introduce SoPhy to the patient by the physiotherapist. During this face-to-face consultation, patients were required to wear the SoPhy socks and then continue with the consultation as normal. For hygiene purpose, the patients wore the SoPhy socks on top of their own socks, or on top of thin stockings that we provided. The physiotherapist used the SoPhy web-interface to
read the movement related data of the patient. The SoPhy screen was placed in a corner of the room to support clear visibility to everyone (refer Figure 3).

**Session 2: Video Consultation (45–50 min) and Face-to-face follow-up (15–10 min).** The aim of the second session was to understand the use of SoPhy in video consultations. This session consisted of two parts – first a video consultation organised at two rooms of the hospital, and second a short face-to-face follow-up. The total session duration remained 60 min. This structure of the sessions was based on a previous field study for surgery related video consultations [Stevenson 2011], where the author evaluated the use of multiple webcams (media spaces) to provide details of patients from different perspectives to the remote surgeons in video consultations. In this study, all the sessions were organized at the hospital premises and the patients met their surgeons directly in the video consultations. A short face-to-face follow-up was allowed after the video session to allow discussion of topics that cannot be discussed over video.

For the video consultation, the patient and physiotherapist were in different rooms at the hospital and met each other over video. In both the rooms, two screens: one for the video call and another for the SoPhy web-interface, were arranged in the similar manner (see Figure 4). SoPhy web-interface was also presented to the patient to support conversations around the visualisation. Additionally, learning from our previous study [Aggarwal et al. 2016], we started the web-interface 5–10 min before starting the video call. This was done to extend the opening phase of the video consultation. Patients and physiotherapists followed the same tasks as followed in the first session.
The video consultation was followed by a short face-to-face meeting, where the physiotherapist came over to the patient’s room to discuss any unresolved issues that were not discussed during the video consultation. The follow-up was organized only at the end and not in the beginning so that the physiotherapist meets the patient for the first time over video. For instance, a face-to-face meeting before the video session would make the video session less significant, as physiotherapists can formulate an initial assessment of the patient by meeting them in the collocated setting. These follow-up sessions followed an open structure and there were no prescribed activities for the patients and physiotherapists.

4.2 Participants

The study was conducted with one physiotherapist (pseudonym: Phil) and three patients for a period of five months. The collaborating department had two physiotherapists who were recruited for the study, but only one of them had patients with lower limb issues during this study.

We conducted the study with three patients—Sally, Paige, and Erica (pseudonyms). These patients were between 11 and 17 years of age at the time of the study. Table 1 provides a list of the sessions observed with each patient along with details on their health status. All patients had different chronic pain conditions associated with lower limbs that were contributed by a mixture of psychological, social, and biological factors. All patients were struggling with normalised weight bearing. Normalising weight bearing is one aspect of the lower limb rehabilitation, where the aim is to teach patients about how to distribute their weight normally over the foot [Chalkiadis 2001]. Patients with long-term chronic conditions lose sensations about how to bear weight normally on their foot and are fearful of putting weight on the affected body part because of pain. Hence, the rehabilitation goal for patients is to get them back to their daily routine that they followed before their clinical condition, e.g., being able to do everyday routine activities normally, or being able to perform a certain activity like sports or dance.

Sally was diagnosed with Complex Regional Pain Syndrome (CRPS) in her right foot and suffered an injury in her left knee. She had high pain in both legs but was particularly anxious of bearing weight on her left foot. She
Paige had chronic pain in her left leg. She was using crutches to walk. She had high pain in her left leg and was highly anxious of bearing weight on left foot. Her x-ray scans were normal, and she was diagnosed with Pain Amplification Syndrome. She was a perfectionist, a highly anxious and sensitive person—these factors contributed to her pain experience. Her rehabilitation goal was to normalize weight bearing on her left foot.

Erica had chronic pain in the bone under the big toe of her right foot. She was also using crutches to walk. She had high pain in her right leg and was highly anxious of bearing weight on her right foot. She had Sesamoiditis—chronic inflammation in the small bone at the base of her big toe. She was also a highly anxious and sensitive individual, with an amplified pain system. Her pain experience was thus contributed by both biomechanical and psychological factors. Her rehabilitation goal was to normalise weight bearing on her right foot.

The condition of these patients changed over times, which influenced the course of the study. For instance, we conducted an additional face-to-face session with Paige after conducting one face-to-face and video consultation (session 5). This session was organised as a face-to-face consultation and not as a video consultation, because the session required involvement of multiple clinicians like occupational therapist and psychologist, which clinicians found challenging to pursue over video. Since Phil was interested to assess her improvement with SoPhy, a face-to-face session was organized. However, we conducted only one session with Erica, because her condition deteriorated after the session, and she went through a clinical procedure. As a result of which, normalising her weight bearing was no longer the immediate treatment goal.

Several reasons contributed to low number of participants. First, the study was focused only on patients with lower limb issues. Lower limb rehabilitation is one of the several conditions for which the hospital department offers treatment. Second, not all patients with lower limb issues participated in the study. Some of the patients were considered too vulnerable to try out a wearable technology. Furthermore, some potential patients did not participate, because after making the physical trip to the hospital, they preferred to meet their physiotherapist in the face-to-face setting. Making a trip to the hospital typically involves skipping school and a couple of hours of commute.

### Table 1. Details of the Sessions Conducted with three Patients and one Physiotherapist (Phil)

| Patients | S. No. | Session Type | Time since previous session | Other attendees |
|----------|--------|--------------|-----------------------------|-----------------|
| Sally    | 1      | Face-to-face | –                           | Mother          |
|          | 2      | Video        | 1 week                      | Mother          |
| Paige    | 3      | Face-to-face | –                           | Mother          |
|          | 4      | Video        | 1 week                      | Mother          |
|          | 5      | Face-to-face | 3 months                    | Mother, Psychologist, Occupational Therapist |
| Erica    | 6      | Face-to-face | –                           | Mother          |

*Condition describes the patient’s health status in the beginning of the study.*
4.3 Data Collection
As the study was conducted with patients under 18 years, we aimed at keeping the setting natural and comforting for the patients during the study. Blandford et al. [2015] emphasized on employing non-intrusive methods like observations, informal conversations and post-session interviews for making participants comfortable in the hospital setting. Building on their guidelines, we conducted observations of both the video and face-to-face sessions to understand when and how the physiotherapists and patients used SoPhy. Since the study aimed at understanding the clinician’s experience, all the observations were conducted from the clinician’s end. These observations were taken as field-notes, which were elaborated after the session.

Additionally, informal conversations were conducted with the physiotherapist to reflect upon the latest event in a think-aloud manner. These conversations lasted for a couple of minutes and were noted down as field-notes. These conversations were initiated when the physiotherapist was setting up for the consultation and when there were technical issues. Finally, photographs of the room and patients, focusing on the foot and SoPhy socks, were captured to record the use of SoPhy in different sessions. Although these photographs did not become part of the data analysis, they were particularly used to describe the insights about the interactions between patients and physiotherapist.

After the consultation, we conducted semi-structured interviews with the physiotherapists and patients to understand their overall experience with the designed system. In total, eight interviews were conducted with Phil: (1) one after each session to understand the use of SoPhy in the immediate session; (2) one in the middle of the study to reflect upon the use of SoPhy by then; and finally (3) one at the end of the study to reflect upon the overall use of SoPhy for all patients. These interviews lasted for 40–90 min. However, conducting interviews with the patients was difficult, because these patients had consultations with other clinicians immediately after the session. We managed to conduct interviews with Sally and Paige after sessions 2 and 5, respectively. Interviews with the patients were conducted in the presence of their carer and lasted for around 20 min. All the interviews were conducted at the hospital and were audio-recorded for later analysis.

4.4 Data Analysis
To understand the clinician-patient interactions with and around SoPhy, we utilised the six phases of a consultation [Byrne and Long 1976]: Opening, History Taking, Examination and Diagnosis, Treatment, and Closing. Employing thematic analysis approach, we followed both inductive and deductive approach [Braun and Clarke 2006] to analyse the collected data. The data analysis was intertwined with the data collection process, and we started reflecting on the data right from the first session. Inductive analysis allowed new themes to emerge from the data related to the utility of SoPhy for patients and physiotherapists at different times, whereas the deductive analysis helped us to structure the findings around six phases of a consultation.

The first author coded the data on paper and created memos to capture emerging ideas and trends across sessions. These ideas were regularly discussed with other authors for deeper analysis of the data. Additionally, using Member Checking [Cho and Trent 2006], the themes and sub-themes were also discussed with the collaborating physiotherapist (last author) to validate our interpretation of the data.

Through iterative analysis, we structured the findings across six themes: Opening, History Taking, Examination and Diagnosis, Treatment, Closing and Challenges with SoPhy, with each theme consisting of multiple sub-themes. While the themes provided context to the activities between patients and physiotherapist, the sub-themes highlighted what component of SoPhy (i.e., socks or visualisation) supported the activity. We merged the Examination and Diagnosis phases as all the consultations were follow-up sessions with no new examination. We also encountered some challenges with SoPhy that are discussed separately under “Challenges with SoPhy.”

5 FINDINGS
Below, we present the study findings across six themes. Findings are enumerated around the names of the phases, e.g., O1, O2 for opening phase, and so on. Within each theme, along with the instances from video consultations,
we also provide some instances from face-to-face consultations that are particularly relevant to video consultations. Also, due to privacy provisions, we did not undertake video recordings of the participant sessions. The images in the findings are recreations from field notes that are used to illustrate particular features of the SoPhy visualisation. Hence, images are only representative of the actual visualisation seen by the participants during the sessions.

**Phase 1: Opening**

The Opening is the introductory phase of the consultation, where the patient and physiotherapist first meet. There are two findings related to the use of SoPhy for this phase.

*O1: Putting on the Socks Offered Early Insights on the Patient’s Condition.* The act of putting on the SoPhy socks offered early insights to Phil regarding the patient’s emotional and physical state. For instance, when patients were in pain, they did not allow anyone to touch their foot. Also, they were very careful while wearing the socks. Phil observed in which foot the patients wore the sock first, whether they asked for any help from their parents, and how easily they were able to wear them. Although such observation is possible with any other socks, this incident highlights how SoPhy socks became a medium to offer rich incidental cues to physiotherapists.

In video consultations, the SoPhy web-interface was connected a couple of minutes prior to the video connection (as per the study protocol). Through the SoPhy visualisation, Phil could understand how patients have arranged their feet, and anticipated the kinds of activities patients were doing. For instance, in session 2 with Sally (video consultation), Phil interpreted the SoPhy web-interface in the following manner, "Okay, Sally is putting on the socks now, first in the left foot. The toe sensor is still orange, but it is consistently orange. Now she is putting on the socks in the right foot. So, her weight is on the heel of the left foot, no no, her left foot is almost flat, all circles are colorful, 'that’s good Sally!’" Hence, through the web-interface readings, Phil understood that Sally had started using her left foot more normally. Sally had pain in both legs due to which Phil was checking on the visualisation readings for both feet. Consistency in holding one color on the right foot and the fact that Sally had started to put her left foot (affected foot) flat, both showed the improvements in her condition.

*O2: Visualisation Made Incidental Movements of the Patients Visible.* Physiotherapists typically observe incidental movements of the patients such as walking, sitting, and talking style, as these movements are performed unconsciously by the patients and therefore, offer true reflection on their health status. The SoPhy visualisation increased the availability of the incidental cues in both the face-to-face and video consultations right from the start of the session. In face-to-face sessions, it highlighted the mundane activities like sitting posture of the patients, which were easier to ignore because of the ongoing informal conversations at the start. In session 1 (face-to-face), as soon as the SoPhy interface was connected, the room was filled with excitement. Sally was sitting on a chair with socks on, and the interface presented her sitting pattern (see Figure 5). With great joy, Phil said, "Wow! We have not seen you sitting down. This is great! Can you describe me what are you seeing here [pointing to the interface]?” Sally smiled and said, "I am putting more weight outside than on inside—something that you have been telling me.”

Similarly, in video consultations, the visualisation offered insights into how patients arranged their lower body while talking to the clinicians. In session 2 (video consultation), Sally sat closer to the webcam such that the webcam captured her upper torso. While having conversation with Sally, Phil referred to the SoPhy interface to understand her lower body arrangement. He noticed that for both feet, pressure sensors on the balls were in orange-red spectrum (refer Figure 6). He was curious to know the reason behind this visualisation, therefore, he said, "Now Sally, please stay at the same position. Don’t move. I am trying to understand your foot position through this interface. What are you doing right now?” Sally mentioned to be sitting in the tip-toe position. Phil was delighted to know that and with a laugh he said, “This is amazing! I can see what’s happening with your feet
Phil then asked her to try to put her feet flat on the ground, and from there the session unfolded to the next phase.

Phase 2: History Taking

History Taking is the second phase where the patient describes the changes in his condition. There are two findings related to the use of SoPhy for this phase.

\textit{H1: Consistency in Holding Colors of Visualisation Illustrated Patient’s Recovery.} When the patients were performing the exercises, Phil observed the duration for which the patients could fill in the colors at three pressure points on the affected foot. This observation helped him to evaluate the patient’s consistency in performing exercises. Phil described consistency as a key factor in rehabilitation, because it helps patients in building up a routine and gradually helps them to achieving their goal of effectively doing everyday activities. Phil described how he assessed Paige in session 3 (face-to-face): "Today, she was mostly in the orange color spectrum but was getting hotter colors only for a short while. So, I could see that she started to put her foot down, but her progress is very slow." (The visualisation for weight distribution is graded with orange color showing light pressure and red showing more pressure.)
However, consistency in getting similar colors on certain areas and not on other areas also shed insights on other physical aspects of the patient’s condition, that were not described by the patients otherwise. For instance, in session 1 (face-to-face), when Sally was demonstrating different exercises, Phil noticed that she was not able to hold the colors of heel sensors for a long time, whereas her consistency for ball sensors (affected area) had improved. This inconsistency in colors was more evident when she was doing the assisted squats, where she was going down only for a little distance and then quickly coming up. Through this, Phil understood that Sally might be having muscle tightness in her calf region, and said, “Sally can you see that the heel sensors are orange when you are doing the squats. How are you feeling here in the calves [touching his calf]?” Sally described the tightness in her hamstrings. Phil then examined it by pressing the calves and nearby area for both legs.

**H2: Visualisation Highlighted Subtle Differences in the Patient’s Movements.** SoPhy helped Phil to distinguish the subtle difference in the patient’s movements in both face-to-face and video consultations. In session 1 (face-to-face), when Sally was demonstrating her walking, Phil noticed the difference in her foot striking patterns through the visualisation. Seeing this, Phil pointed towards the pressure sensor under the big toe of the left foot and said, “Did you notice something here Sally? Your right foot is going through a process – it starts from light color and then slowly reaches to red color, whereas your left foot directly reaches to red color. Your left foot also needs to go through the same process- first you strike the ground with your heel, then you touch the balls of your foot and then you take off slowly. Now walk again and only see the toe circles.” Sally then performed some repetitions for walking and continued to see the visualization for feedback. Later in the interview, Phil appreciated the visualisation in the following way: “Being able to see what was happening there so clearly in real time was a real surprise for me.”

Phil also appreciated the visualisation of weight distribution (and foot orientation), as it highlights the exact locations where the patient was bearing the weight and where they needed to improve. He compared the accuracy of SoPhy with the typical practice of physiotherapists, where they utilise weighing scales to understand the amount of weight the patients can bear on their affected foot. He described that weighing scales do not provide an accurate assessment, because “they [patients] could easily cheat by pushing through their toes or through their heel—the scales would still indicate more weight.” Knowing the potential of SoPhy and the weighing scale, Phil used both of them in session 5 (face-to-face) to understand Paige’s progress. Paige was working toward bearing her full body weight on her left leg. Hence, in this session, when Paige was pushing through the scale wearing the SoPhy socks, Phil checked the interface and noticed that the sensor under the big toe was orange, while the other sensors were red (refer to Figure 7). This assured Phil that she was not pushing the weighing scale from the outward side of her foot but was also bearing weight on the inside of her foot.
Phases 3 and 4: Examination and Diagnosis
This phase involves physical or oral examination of the patient. We combined these two phases, because all sessions were follow-up sessions, and therefore, did not involve fresh diagnosis of the patient’s condition. We have three findings for these phases.

E1: Visualisation Revealed the True Ability of the Patients. Information presented by the SoPhy visualisation helped the physiotherapist to understand the true ability of the patients. Patients often demonstrate contradictory behaviours when their movements do not match with their verbal description, which was particularly the case with Paige. Phil narrated one instance from session 3 (face-to-face), when technical difficulties with SoPhy highlighted that Paige could do better than what she was doing at that time. He said: “She was standing, and she felt that the device was not working. So, she pressed her left foot harder on the ground. And that was the first time she got the biggest circle with all red colors. But she quickly lifted her foot up. That showed me that she could do better in weight bearing, but for some reason she wasn’t doing it.”

At another time, in session 4 (video consultation), SoPhy helped Phil to understand that Paige was not trying harder than what she was describing verbally. While trying exercises in the session, Paige described all the exercises as very painful. Along with the verbal complaints about pain, she was also making groaning sounds like aah and mmm. These expressions illustrated that she was putting in significant efforts in doing exercises despite of the pain. However, Phil noticed that these behaviours were contrary to the visualisation readings. The toe sensor for her left foot consistently remained on the yellow-orange color, highlighting that there was no difference in her movements. Phil then observed other bodily cues such as her face color and breathing patterns to understand her actual recovery. Later, in the interview, Phil appreciated the support from SoPhy in the following way, “When people are in pain, their face looks pale, they will sweat, there is muscle tension, or they will hold their breath. But she did not have any of that. She was not doing anything different today, because I could see here that the colors were not changing.” Through these observations, Phil was assured that the current treatment was not working for her and that he would need to try out some other treatment strategy with her.

E2: Visualisation Corrected the Clinician’s Hypothesis. SoPhy helped Phil in correcting his assessment in both face-to-face and video consultations. It provided new insights that either he was not anticipating, or he could not observe directly. In session 6 (face-to-face), SoPhy corrected Phil’s assessment by highlighting that Erica was putting more weight on the balls of her right (affected) foot than he was anticipating. When she was demonstrating her walking with crutches, the right foot sensors showed orange color on the balls. Phil was surprised seeing it and he said, “You are putting more weight than I thought you would—there is a lot of improvement!” To this, Erica said, “I have been practicing a lot at home.”

In session 4 (video consultation), Phil thought that Paige was bearing good weight as her foot looked flat on the ground when she was standing. Although her feet looked flat, she displaced her weight through her arms, as she rested her hands on the crutches. Since the aim is to encourage patients to put their foot flat and she appeared doing the same, Phil thought that she had improved. However, the interface showed that the left foot sensors were on the lower color spectrum with smallest circles—which corrected Phil’s observations. Later in the interview, Phil stated that, “For me, it looked normal—her foot was flat on the ground and she was standing relatively straight. But the device showed me that there was only a fraction of weight going through her feet. My visual capacity is very high. But for SoPhy to show something so small, that’s pretty revealing. The device was fantastic for that to let me know really clearly that she has not got to that point yet.”

E3: SoPhy Increased the Clinician’s Diagnostic Confidence. The rich information provided by the visualisation increased Phil’s confidence in assessing the patient’s progress in both face-to-face and video consultations. He referred to the interface to get confirmation on his hypothesis or to correct his assessment in instances when visual cues were deceitful. As he quoted, “With SoPhy, I have more sense of clarity of my assessment. I did feel
more confident with it. It confirms what I have been thinking, takes it further or disputes it but it gives me more information.”

Because of the support from SoPhy, Phil described it as a valuable resource in both face-to-face and video consultations. However, he valued it more in video consultations by saying: “In face-to-face, SoPhy is secondary or one of the several tools we have for assessment. It works with my observations and mainly confirms what I am already thinking. But in video, it becomes a major way of assessing what they are doing. I am much more reliant on it. Otherwise, I only have what I can see on the screen.”

Phase 5: Treatment
In this phase, physiotherapist suggests treatment to the patient based on his assessment. We have three findings for this phase.

T1: Visualisation Guided More Specific Treatment of the Patients. As assessment directs treatment, greater confidence in assessment increased Phil’s confidence in treatment as well. Through SoPhy, Phil got a better understanding of what was happening with the patient and whether the treatment was working for them. The information then helped him to validate and appropriate the treatment to make it more suitable for the patient.

Throughout the study, there were different scenarios of how Phil changed the treatment at different times to make it more suitable for the patient. With Sally, he upgraded the treatment to next level after realizing her significant improvement in weight bearing. In session 2 (video consultation), Phil observed that Sally could get red colors throughout on both feet. Phil tested her ability by asking her to perform different weight-bearing exercises, and conducted oral examination to inquire about her fatigue, and muscle tightness. He was assured that she had improved in weight bearing and therefore, he upgraded the treatment from weight bearing to improving her endurance and muscle flexibility. Consequently, in the later part of the session, Phil practiced a completely new set of exercises with her, including calf stretches, knee extensions, 1-leg stance, 1-min step test, and low squats.

At other times, Phil withdrew the treatment by seeing negligible progress of the patient, as was the case in session 4 (video consultation). Seeing the way Paige was performing the exercises, Phil understood that the treatment was not working for her. For example, the pressure sensors on her left foot remained on the yellow color for all the movements she performed. She was too scared to try out anything that she was not able to progress. Phil thought that continuing with the same treatment was not fruitful. Hence, he took a step backwards from weight bearing and shifted the aim to body awareness for the next consultation.

Finally, with Erica, Phil used SoPhy to moderate her movements such that she could better manage her everyday activities with her high pain condition. In session 6 (face-to-face), when Phil found out that she was bearing more weight on the balls of her right foot while walking, he became cautious, because for her condition she should be bearing less weight. Hence, Phil worked with her to practice how to bear weight on her right foot for three exercises: sitting, standing and walking.

T2: Visualisation Became the Language to Suggest Treatment. SoPhy provided a common language to the patients and physiotherapist to communicate. Phil utilised the characteristics of the visualisation such as colors, circle size, and position to discuss the patient’s recovery and to plan the therapy goals. He appreciated the visualisation in the following way, “The interface enormously helped in the communication. It gives me three different sizes, and it gives me all those different colors and different areas that I can use to work with my clients. I can say, ‘Let’s make it a bigger circle,’ ‘See if you can get them all in the same colors,’ or ‘Let’s try to hold it there.’”

SoPhy visualisation proved very helpful, particularly for Erica in session 6 (face-to-face), as Phil could better communicate the differences in her therapy goals. Since she was in the early stage of her rehabilitation, the aim was to encourage normalised weight bearing in sitting but less weight bearing in functional activities like walking and standing. Phil worked with her to normalise her weight bearing in the sitting position. He utilised
circles on the interface to highlight her goals in the following way, "What you need to do is to make the front circles on your right foot of the same size." However, for standing and walking, he suggested her to put very little weight on the bone under big toe of right foot, while bearing more weight on the hands and crutches. To make her clear about how to bear less weight, Phil asked her to get light yellow color on the affected area. He said, "Yellow color is fine here. Don’t bear more than this!" (refer to Figure 8)

SoPhy also became a language to discuss the patient’s progress. In session 4 (video consultation), Phil compared Paige’s progress with the previous session around the colors for weight distribution visualisation. He said: "You were putting more weight on your left foot when you were testing the device in the last session. Today, there are hardly any colors than yellow-orange. The only thing you did differently today was to get brown color on the heels for about 7 seconds and that was longer than what you did before."

Better communication with patients enhanced Phil’s confidence in trying out new activities, particularly during video consultations. With SoPhy, video consultations became interactive with Phil asking the patient to try out different exercises in succession. The sessions became spontaneous and Phil performed different activities that he has not tried over video ever in his practice. For instance, in session 2 (video consultation) with Sally, Phil tried a completely new set of exercises that included calf stretches, knee extensions, single leg stance, 1-min step-up test, and deep squats (see Figure 9).
Phil was very pleased seeing the changes in his practice of organising video consultations. In an interview, he said, “Normally, I do not try out new exercises over video, because I don’t know how good they are following me. With SoPhy, I went through different exercises with them, ‘Can you do this, ’ ‘Can you do that.’ It was clear then that they knew what I was talking about. It [SoPhy] is a common shared experience now.”

**T3: Visualisation Made the Therapy Goals Achievable for the Patients.** SoPhy visualisation made the therapy goals explicit to the patients. First, it highlighted specific small areas where they need to work on. Patients could make simpler goals using the characteristics of the SoPhy visualisation such as colors, size and position of the circles. As described by Sally in an interview, “It is difficult to understand what to do and how to have normal walking. But with this [interface], you clearly know that you need to fill this circle with red color.”

Secondly, through SoPhy, patients received real-time feedback on the little changes in their movements that were difficult to understand otherwise. Without SoPhy, patients had uncertainty about how much weight they were bearing, and how their weight distribution patterns changed for different movements. Phil described that the presence of SoPhy made a significant difference, because it allowed them to see what is going on with them and how things change with different movements. As he noted: “When we say, ‘You know, you are not putting your foot down as much. You need to work on the weight going through this part.’ Whatever they do, there is no way to see the difference. But SoPhy showed them the difference. They can see how their efforts shape up in the form of color or size. SoPhy led them to adjust and compare and to continue—all at the same time.”

Finally, the visual feedback encouraged functioning of different senses in the patients and pushed them to do better. Because all the patients had long standing chronic condition, the continuous feedback helped them to feel the lost multi-sensorial sensations of how it feels like to perform movements normally. This multi-sensorial sensation helped the patients to overcome their anxiety and fear of bearing weight on their foot and helped them to better concentrate on their movements. In the interview, Sally described herself being more confident in doing the exercises because of the real-time visual feedback. She said, “It gave me lot more ability to do the movements fluidly. I was confident that my foot can take the pressure, and I could see it clearly.” After realising the importance of the visual feedback, both the patients and their parents showed interest to continue using SoPhy at home.

**Phase 6: Closing**
Closing is the last phase, where the clinician ends the consultation. We have one finding for this phase.

**C1: Taking Off the Socks Created Opportunities for Informal Conversations.** Taking off the SoPhy socks created opportunities for Phil to introduce informal conversations with the patients. When patients were taking the socks off, they continued talking about what worked and did not work in the session. They talked about the best moments with SoPhy, the peak color they could achieve at the affected area and the breakdown times of SoPhy. In this way, SoPhy created opportunities for patients to express their emotions about the consultation and their progress. However, Phil assessed the emotional standing of the patients by observing how the patients were taking the socks off and what kinds of conversations they were raising.

Ending of the sessions varied for different patients. For example, both the sessions (sessions 1 and 2) with Sally ended on a positive note. Sally made significant progress in both the sessions and she was very happy with it. In both the sessions, she demonstrated certain dance movements to get Phil’s confirmation if the movements were fine for her to perform. She wanted to resume her dancing shortly. In session 2 (video consultation), when Phil came down to meet Sally for the face-to-face follow-up, he demonstrated her some new exercises in response to her curiosity. After session 2, Phil described Sally’s behavior in the following way, “That was an example of feeling confident. She was so impressed and delighted with her progress that although we had finished, she wanted to learn more.” Phil did not demonstrate any new exercise in other sessions. With Paige and Erica, he discussed different strategies of managing pain and encouraged them to overcome their anxiety.
Challenges with SoPhy

The study also highlighted certain technical difficulties of using SoPhy in the session. Some of them were anticipated issues, e.g., Bluetooth disconnections during the course of a consultation, and the delay in rendering the sensor values on the visualisation. However, these issues did not significantly change the overall use of SoPhy in the consultations. One issue that somewhat influenced the clinician-patient interactions was the lack of opportunity to revisit the exercises in video consultations. Patients wanted to refer to the visualisation for every exercise, which, however, was not possible in video consultations. This was because patient’s orientation with respect to the web-interface changed for different exercises and for certain exercises like walking, they were not facing the visualisation. Some other times, patients closed their eyes to concentrate on the exercise and, hence, could not see the visualisation. Unlike video consultations, patients and physiotherapist found a solution for this challenge in the face-to-face consultations. Phil made video recordings of the visualisation and of the patient’s movements with the help of the patient’s carer. He watched these recordings post-exercise with the patient to discuss the progress and to plan the next therapy goals.

Another issue was related to the small variations in the color spectrum of the weight distribution, which limited the communication between patient and clinician to some extent. The SoPhy visualisation presents weight distribution on a continuous color spectrum from light yellow to dark red, where the color gradually changes over three categories of weight (low, medium and high). These small variations made it challenging for Phil to directly refer to these colors in the conversations, as described by Phil: "What I wanted to do was to associate the color and the size with movements. But the acuity of different colors is less clear." Consequently, Phil referred to the colors in other ways, e.g., "go for the topmost brown color," where brown color denoted the darkest color in the spectrum. Moreover, in face-to-face sessions, he touched the SoPhy interface to highlight the patient’s progress and the next goal through the color spectrum.

6 DISCUSSION

This study reports on an evaluation of how SoPhy guided physiotherapists across different phases of a video consultation. Both the visual and wearable components of SoPhy supported the needs of the physiotherapist and patients at different times. SoPhy was used by three patients with chronic pain and proved useful for all of them in different ways. All these patients had different conditions and sought different kind of support from SoPhy. They all had anxiety in bearing weight on their affected foot and had learnt that putting weight causes pain. Chronic pain is different from other types of pain like arthritis, cancer or surgery, as in later cases the pain is dealt well with medication [Chalkiadis 2001]. However, with chronic pain, there is a lot of uncertainty, e.g., as to why it is there, how long it will remain and what therapy will work. SoPhy offered specific, observable and real-time information on how patients were using both their feet and encouraged them to do better. SoPhy highlighted the subtle variations in their efforts and, hence, was appreciated by both the patients and physiotherapist. Incomplete understanding of the patient’s health status reduced their confidence in assessing the patient.

6.1 Addressing Challenges in Video Consultations

To highlight the impact of SoPhy in video consultations, we now discuss our study findings with respect to the existing challenges with the standard video consultation practice. This comparison is based on findings in our previous study [Aggarwal et al. 2016], which highlighted challenges faced by physiotherapists across different phases of a typical video consultation. Making the comparison will highlight the influence of SoPhy on both the physiotherapist and patients in video consultations (see Table 2 for a summary). Challenges listed in our previous study are listed as Ch1, Ch2 and so on, and the findings of this study use the names around the phases, O1, H1, and so on.

SoPhy helped to resolve all the challenges identified in our previous study, except for Ch2 and Ch5. Involving multidisciplinary clinicians (Ch2) still remained a challenge in this study because of which, sessions involving
multiple clinicians were not organised over video. This issue also influenced the course of this study and the third session with Paige was organized in the face-to-face setting instead of a video consultation. However, we did not observe any awkward moments in our study (Ch5), because all the exercises were performed in sitting and standing positions. Awkwardness could have been an issue if the sessions involved patients doing exercises lying down on the bed (e.g., leg lifts or thigh lifts) or going away from the webcam, limiting their understanding of their field-of-view.

SoPhy helped the physiotherapist formulate their initial assessment from the opening of the video consultation by providing rich insights on the patient’s emotional and physical state. In the Opening phase, physiotherapist was able to understand the unconscious and incidental movements of the patients while they were putting the socks on; and when they were having informal conversations while preparing to sit down before the formal consultation. Such observations are not possible in standard video consultations [Aggarwal et al. 2016], because traditional video consultation started with the patients directly seated in front of the camera and the webcam focusing on the upper torso (O2, Ch1). Since everyone has already taken up their seat, physiotherapists had little opportunities to raise small talk with the patient (O1, Ch3). Additionally, in this study, physiotherapist had more insights, because we started the SoPhy web-interface 5–10 min before starting the video call. As such, both the SoPhy and procedure made this phase more informative for the physiotherapist and he could build upon his initial assessment in the remaining session.
In the History-taking phase, SoPhy visualisation became a crucial source for the physiotherapist to understand the patient’s recovery. The visualisation revealed fine details of the patient’s lower limb movements, which are not observable over video (H1). Phil got insights about the patient’s anxiety and strategies of weight-bearing patterns by observing the patient’s consistency in holding colors on specific locations of the visualisation. Consequently, he was not reliant on the verbal explanation of the patients, which is the major source of information for the physiotherapists in standard video consultations [Aggarwal et al. 2016] (H1, Ch4). Verbal confirmation is not sufficient, because often patients do not know what is happening with them (Aggarwal et al. 2017; McGough et al. 2012). The visualisation also revealed information as subtle as the walking pattern of the patients that are difficult to eyeball even in the face-to-face setting and are not observable in standard video consultations (H2, Ch6). Information related to weight distribution both between the foot and across each foot, was particularly found useful by Phil and the patients. Weight distribution revealed deeper insights into the patient’s anxiety and pain intensity that are otherwise challenging to observe over video. Hence, SoPhy addresses a different type of movement (weight bearing) than the one reported in the existing literature around technologies for physical rehabilitation [Ananthanarayan et al. 2013; Ayoade and Baillie 2014; Lam et al. 2016; Ploderer et al. 2016; Tang et al. 2015].

Although assessment of the patients was limited to oral examination, because physical examination cannot be conducted over video, SoPhy offered other ways to conduct in-depth oral assessment of the patients (E2, E3, Ch7). First, SoPhy helped the physiotherapist in assessing the patients through the quality of their movements. It highlighted the subtle differences in the movements that were otherwise not visible or misleading over video. Crucial bodily information like body tightness were observable from the History-taking phase, which helped the physiotherapist to continuously refine his assessment. The ability to distinguish such subtle differences corrected the physiotherapist’s assessment at certain instances and made their assessment timely and accurate. Second, SoPhy socks became a probe to support covert examination, which is otherwise challenging to conduct in standard video consultations, because artefacts in the immediate surroundings of the patients are out-of-the-view of physiotherapists (E1, Ch8). Patient’s interactions with SoPhy highlighted their health status throughout the session. For instance, during the breakdown of SoPhy, Paige put all her weight on her affected foot to check if the system was working. From this single interaction with SoPhy, Phil received critical insights on her actual ability and her anxiety levels in trying out new things. This is a novel finding as previous works [Blandford et al. 2015; Blandford 2018; Fitzpatrick and Ellingsen 2013] always emphasize on developing robust prototypes/systems for hospital use. In contrast, our study highlights the benefits of technical breakdowns, which are common and prone to happen even in well-developed systems. Finally, SoPhy enhanced the confidence of the physiotherapist in assessing patients and guided more detailed and accurate assessment of the patients than what is possible in standard video consultations. These findings are in line with the insights of the laboratory evaluation of SoPhy [Aggarwal et al. 2017], where SoPhy increased the diagnostic confidence of participants in assessing movements over video.

Better understanding of the patient’s recovery guided more specific treatment of the patients. The physiotherapist was able to validate the effectiveness of his treatment for a patient at different times. With SoPhy, the physiotherapist was able to adjust the treatment in every session to make it more suitable for the patient’s current health status. Conducting treatment over video is novel, because our previous study suggests that the physiotherapists were hesitant to suggest any new exercises over video (T1, T2, Ch9). Additionally, SoPhy visualisation enhanced the clinician-patient communication as it offered a common language to talk about the non-verbal bodily cues (T3). Patients were able to better understand their therapy goals through the visual feedback. They had a black and white understanding of their pain and the device helped them to grade their pain over different factors such as number of sensors, sizes of the circles, color sensitivity of the circles and comparison between the feet. This extra level of monitoring encouraged the patients to try something that they had unlearned over years, and they could vary their movements around different factors. They were able to make simple goals through the visualisation, achievement of which increased their confidence on their capability. As such, with SoPhy, the
consultations became interactive, and both the physiotherapist and patients tried out new exercises in the session. These findings are in line with the previous studies, e.g., Lam et al. [2016] and Singh et al. [2016], where the representation created from the sensed movements were seen by both clinicians and patients as the body space to (co)reason on, (co)discuss, and (co)understand.

SoPhy continued to help the physiotherapist in assessing the patient until the end of the consultation. In fact, it became an excuse to extend video consultations, as the patients were required to take off the SoPhy socks. Phil got opportunities to initiate informal conversations with the patients, which helped him to understand their physical and emotional state. This addresses the issue of standard video consultations, where the ending is short, and the physiotherapists are reliant on the verbal explanation of the patients to understand any outstanding issues (C1, Ch10).

6.2 Supporting Video Stream with Movement Data Visualisation
With SoPhy, we chose to present the visualisation on a separate screen for the physiotherapist to support the video stream, rather than to modify the video stream, or even replace it with a collection of visualisations on a dashboard. The decision was guided through discussions with the collaborating physiotherapist. The reason being that SoPhy visualisation only played a secondary role for physiotherapists as they still need to focus on the video stream to formulate their initial assessment. They study also highlighted that the physiotherapist switched their attention from video to visualisation whenever he needed additional information from SoPhy. The visualisation confirmed, disproved or added more data to support his assessment—factors that describe the effectiveness of a technology for clinicians [Fryback and Thornbury 1991]. The separation of visualisation also proved helpful for treating patients in video consultations. The visualisation provided both a language and measurable goals to be reached when new exercises were introduced, which also helped patients to shift attention away from their body and the pain towards their movements. Patients started focusing on achieving different colors on the screen, and in pursuit, they tried different ways to bear appropriate weight on their affected foot.

These findings are different from the existing literature, where the feedback has been presented in different locations, modalities, and temporalities. In terms of location, one consideration is whether to present visualisation separately or directly on the body, for example, to project information on the body or on the video stream or to present information on a wearable technology worn on the body (e.g., Ananthanarayan et al. [2013]). In terms of modality, feedback could be presented through sound so that the visual attention can stay on the patient’s body (e.g., Newbold et al. [2016], Singh et al. [2016], and Tajadura-Jiménez et al. [2015]). Finally, in terms of temporality, data can be visualised both in real time and as historical data, e.g., as a timeline or a heat map that allows physiotherapists to identify limits in range of motion or trends over time in how patients bear weight (e.g., as in Ploderer et al. [2016]). Different feedback mechanisms offer different benefits, thus should be carefully considered for a given context. With SoPhy, presenting the visualisation on socks (on-body) was not a suitable choice, because patients are always encouraged to look straight to have proper balance, and seeing the visualisation on socks would have defeated the rehabilitation purpose. Additionally, since our research focus was on clinicians, we presented the visualisation on a separate screen, as clinicians are constantly in front of a screen in a video consultation. More research is required to understand whether and how presenting the movement data in a different modality like sound would help clinicians in understanding the patient’s movements.

6.3 Collective Reflection on Therapy Goals
While the aim with SoPhy has been to better support the physiotherapist, we have also seen how it has benefitted both patient and physiotherapist to collectively reflect on the recovery to date and future goals. The visualisation provided reference points for exercises as well as immediate feedback on patient’s movements. Furthermore, it provided a vocabulary for patients and physiotherapy to describe the bodily concerns and exercises. In this sense, the visualisation served as a boundary object [Star and Griesemer 1989], an artifact that supports communication
and coordination between patients and physiotherapists, allowing each side to share their unique knowledge and experiences on matters pertaining to the body, including movement and pain.

As a boundary object, the visualisation was important, because it enabled collective reflection—the process when both the patients and clinicians are involved in discussing the patient’s recovery and to planning the next goals. Collective reflection is important to plan appropriate goals for the patients as per their abilities and is defined as an integral part of the goal-setting theory [Locke and Latham 2006; Winstein et al. 1994]. It speaks to the broader idea of supporting co-interpretation of the patient’s data by patients, clinicians and caregivers [Mentis et al. 2015], as well as utilizing patient generated data for collaborative decision making [Choe et al. 2018].

In video consultations, as patients and clinicians are present in different physical spaces, supporting collective reflection is crucial to better support the clinician-patient interactions. While SoPhy visualisation helped the patient and physiotherapist in reflecting on the therapy goals in video consultations, the use of SoPhy in the face-to-face setting highlighted certain opportunities to further enhance the communication (as discussed under Challenges with SoPhy). For instance, in face-to-face sessions, the physiotherapist frequently touched and gestured towards the visualisation to discuss the patient’s progress. These interactions with SoPhy interface helped the physiotherapist to create a shared understanding of the patient’s goal and made the interactions with patients more fluid. The physiotherapist also video-recorded the visualisation screen to watch it later with the patient. These video recordings particularly proved beneficial when the patients could not refer to the visualisation while doing the exercises, e.g., they closed their eyes to concentrate on the correct movement. This finding is in line with previous studies [Chen et al. 2011; Mentis et al. 2015], where patients and clinicians arranged themselves around the screen to collectively reflect upon the patient’s records. Papi et al. [2016] also described the use of video recordings for face-to-face physiotherapy sessions to enable discussion on unseen subtle movements and to help patients to see progress over time.

The challenges experienced by the physiotherapist and patient with SoPhy also highlight the desire for collective reflection. In particular, we found that collective reflection was affected by the limited amount of detail in the visualization of the weight distribution, which was only visualized through a limited set of colours. This in turn limited the communication for the physiotherapist, who could not verbally refer to different colors. It also affected the patient, who could not easily discern her progress towards therapy goals in between consultations. An obvious suggestion is to add more detail to this visualization, either through a wider range of colours or by providing numerical information, which could aid patient and physiotherapist in their collective reflection. However, as with any visualization, there is a trade-off, and it is conceivable that more detail could increase the overall complexity of the visualization, and in turn take attention away from examining and treating patients. Likewise, the complexity could also affect opportunities for patients to engage with visualizations and their efforts to collaborate in the consultation and reflection.

6.4 Limitations

It is important to acknowledge the limitations of this work in terms of credibility and applicability. First, the study was conducted with a small number of participants, all female patients under the age of 18 years. Further studies are needed to validate its use for male patients and other demographics having chronic pain. Second, having conducted the study with only one physiotherapist may have impacted the findings, as certain activities observed in the study may be due to the particular practices and concerns of the physiotherapist. In terms of credibility, it is conceivable that further observations with other patients and physiotherapists would also provide insight into the influence of SoPhy on challenges identified in our prior work [Aggarwal et al. 2016], i.e., on involving multiple clinicians (Ch2) and the inability to control field-of-view and related awkwardness (Ch5). We also acknowledge that findings may not be applicable to physiotherapy video consultations in other clinics. Finally, we evaluated SoPhy in six sessions (four face-to-face and two video). Although only two were video consultations, we argue that all six sessions present the real-world practice of video consultations. Video consultations are still not a
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standalone practice, because they are organized in adjunct with face-to-face consultations—such a practice was also noted in our previous study [ibid.].

The strength of this study, however, lies in its ecological validity, as the findings are grounded in the real-world practices of hospital video consultations. This study offers a significant understanding of the influence of wearable sensing technology on the clinicians’ practice as well as the complexities of conducting field studies in video consultation settings. Field deployments in hospital setting are time and resource intensive [Blandford et al. 2015]. Consequently, clinical studies of new systems are rare in HCI and those that have been successful are often conducted with a small number of participants. For example, Mentis et al. [2015] presented insights from six surgery (face-to-face) sessions organized by one neurologist; and Kirk et al. [2016] described insights from the home deployment of a new system with three stroke patients who were recruited by one occupational therapist. Video consultations are even more challenging as it requires data collection at two remote ends. Hence, by demonstrating how SoPhy enhanced the effectiveness of physiotherapy video consultations, we make a novel contribution to HCI literature.

7 CONCLUSION

This article presented the clinician’s perspective on using a wearable technology, SoPhy, in physiotherapy video consultations. SoPhy helped in resolving the challenges related to mediating the subtle differences of the patient’s lower limb movements over video. Through SoPhy, we demonstrated that sensing technologies, when designed carefully, can enhance the abilities of clinicians in assessing and treating patients remotely. Our study is the first attempt to make video consultations effective for lower limb rehabilitation. This article is timely and relevant to HCI, since video consultations are largely limited to standard video conferencing focusing on talking heads. The need to understand the subtle differences in the patient’s movements is not only critical in the physiotherapy consultations but is also essential in a wide range of clinical domains. For instance, dermatologists assess subtle changes in the patient’s skin conditions [Dods et al. 2012], and respiratory physiotherapists observe fine changes in the patient’s breathing patterns [Attridge 2008]. However, subtlety of bodily information cannot be solely supported by video technology, as the audio and video streams in a video call are typically adulterated [Mentis et al. 2016]. Sensing technologies are therefore needed to enhance video consultations for different clinical domains. While our work lays the foundation for designing novel systems that can effectively support the practice of physiotherapists in video consultations, the system design and study findings also have implications to other clinical domains relying on bodily data.

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