Supporting Bodily Communication in Video Consultations of Physiotherapy

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Abstract

Physiotherapists are increasingly organising video consultations to support their patients over-a-distance. Physiotherapy is all about movements, and physiotherapists work on improving the subtle differences in the movements to restore the functioning of the affected body part. However, there exists a limited understanding on how physiotherapists assess and treat patient's movements over video particularly when the limitations of video technology in mediating bodily information are already known.

This thesis attempts to fill the gap by investigating how interactive technologies can support physiotherapists in understanding the patient's bodily information during video consultations. To address this question, I conducted three studies each employing a different methodology. Study 1 examined the challenges that physiotherapists face in interpreting patients' bodily information during video consultations through a field study. This study highlighted that video technology limits physiotherapists in understanding subtle differences in patient's movements particularly related to lower limbs. Findings of this study guided the development of a research prototype, *SoPhy* - a wearable technology that monitors lower limb movements of patients over-a-distance. *SoPhy* consists of two parts: (1) a pair of socks with embedded sensors that captures patient's movements; and (2) a web-interface that displays information about weight distribution, range of movement, and foot orientation to physiotherapists in real-time. Study 2 and 3 were focused on the evaluation of the developed prototype first in the laboratory through experimental research, and then in the hospital setting through field deployments. Study 2 showed that *SoPhy* increased the diagnostic confidence of physiotherapists in assessing lower limb movements over video. And Study 3 showed that *SoPhy* enhanced the clinician-patient communication, and guided more accurate assessment and treatment of the patients during video consultations.

This thesis makes four contributions: First, it provides a detailed understanding of how bodily communication is employed by physiotherapists during video consultations. Secondly, it develops an understanding of the limitations of video technology in supporting the tasks of physiotherapists. The third contribution is a novel technology, *SoPhy*, that communicates information of patient's weight distribution patterns over-a-distance to support physiotherapists in their clinical tasks. Finally, the thesis demonstrates that the efficacy of physiotherapists to assess and treat patients over video can be enhanced by using sensing technologies like *SoPhy*. The thesis aims to stimulate interest in designing novel technologies that can support effective assessment and treatment of body movements over-a-distance.

Declaration

This is to certify that

i. where due acknowledgement has been made, the work is that of the author alone,

ii. the work has not been submitted previously, in whole or in part, to qualify for any other academic award,

iii. the content of the thesis is the result of the work that has been carried out since the official commencement date of the approved research program,

iv. due acknowledgement has been made in the text to all other material used,

v. any editorial work, paid or unpaid, carried out by a third party is acknowledged,

vi. appropriate ethics procedure and guidelines have been followed to conduct this research,

vii. the thesis is less than 100,000 words in length, exclusive of tables, figures, bibliographies and appendices or the thesis is [number of words] as approved by the RHD Committee.

Deepti Aggarwal

September 2018

Publications

Major portions of the research presented in the thesis have been peer-reviewed and published in different academic venues. Study 1 and Study 2 have resulted into full publications at ACM DIS 2016 and ACM CHI 2017. *SoPhy* was demonstrated in the Interactivity Research Demo session at CHI 2017 and INTERACT 2017. I also got the opportunity to present this work at several doctoral consortium venues including CHI 2016 and at department doctoral consortium from 2014 - 2017. The complete list of peer-reviewed publications is presented below. These papers are also available in Appendix E for reference.

Aggarwal, D., Hoang, T., Zhang, W., Ploderer, B., Vetere, F., Bradford, M., 2017. SoPhy: Smart Socks for Video Consultations of Physiotherapy. In *Human-Computer Interaction – INTERACT 2017, Lecture Notes in Computer Science.* Presented at the IFIP Conference on Human-Computer Interaction, Springer, Cham, pp. 424–428. DOI: https://doi.org/10.1007/978-3-319-68059-0_44

Aggarwal, D., Zhang, W., Hoang, T., Ploderer, B., Vetere, F., Bradford, M., 2017. SoPhy: A Wearable Technology for Lower Limb Assessment in Video Consultations of Physiotherapy. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems,* CHI '17. ACM, New York, NY, USA, pp. 3916–3928. DOI: http://doi.acm.org/10.1145/3025453.3025489

Aggarwal, D., Ploderer, B., Vetere, F., Bradford, M., Hoang, T., 2016. Doctor, Can You See My Squats?: Understanding Bodily Communication in Video Consultations for Physiotherapy. In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems.* ACM, pp. 1197–1208. DOI: https://doi.org/10.1145/2901790.2901871

Aggarwal, D., 2016. Supporting Bodily Communication in Video-based Clinical Consultations. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, CHI EA '16. ACM, New York, NY, USA, pp. 188–192. https://doi.org/10.1145/2851581.2859019

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Chapter 1
Introduction

Overview: This chapter provides motivation behind this research and outlines the research questions investigated in this thesis.

1.1. Background

Video consultations have emerged as a viable approach to offer clinical consultations to patients with limited access to health services (Ekeland et al., 2010; Fitzpatrick and Ellingsen, 2013; van Dyk, 2014). During a video consultation, clinicians and patients utilise video conferencing tools like Skype to offer diagnostic and therapeutic advice to the patients. Video consultations are often used to support patients living in remote and rural areas. The service is also important to patients in critical conditions or with limited mobility, irrespective of the distance to health services. Such consultations offer benefit patients by reducing the cost and time of traveling to the hospital. They also offer greater opportunities to clinicians to expand their care beyond the four walls of their hospital (Dods et al., 2012b). With the increasing availability of Internet infrastructure and telecommunication technologies in our everyday life, we can expect a further proliferation of video consultations.

Typically, video consultations focus on establishing audio and video connections between clinicians and patients. However, standard audio and video connections might not be sufficient in supporting all the essential clinician-patient interactions particularly the ones that happen through bodily communication like the interactions during a Physiotherapy consultation. Bodily communication refers to the exchange of nonverbal cues that we transmit through our body, consciously or unconsciously, in social encounters (Argyle, 2013). For instance, in a clinical setting, while patients use hesitations and hand gestures to describe their bodily symptoms, clinicians keenly observe such cues to understand the patient’s emotional and physical wellbeing (Heath, 2002, 1986). While bodily communication is critical in clinical consultations in general, it is the fundamental element of the physiotherapy domain.

Physiotherapy is all about movements. In a physiotherapy session, both the patient and physiotherapist are working on the patient's body to discuss therapies and strategies that can improve the body movements (Dillman and Tang, 2015). To assess patient's recovery, physiotherapists must be able to carefully observe fine-details of the patient's bodily movements such as lack of balance while walking or exercising, abnormal distribution of weight in the foot, or limited range of movement in different joints (Attridge, 2008; Friedrich et al., 1996). Besides, their assessment and diagnosis also involve hands-on work with the patients, where they demonstrate and rectify the patient's movements by touching the concerned body part. Based on the assessment, physiotherapists then suggest treatment comprising exercises to help patients in improving their movements and in resuming their normal lifestyle.

While it is well-known that bodily information plays a crucial role for physiotherapists in assessing and treating patients (Attridge, 2008; Friedrich et al., 1996), little is known about how physiotherapists observe and exchange bodily information during video consultations and how do they assess and treat patients over-a-distance. Investigating bodily communication during video consultations becomes crucial as prior studies on video conferencing in non-clinical settings suggest that specific bodily cues get missed when we move our conversation from physical space to video (Dourish and Bellotti, 1992; Gaver et al., 1993; Heath and Luff, 1992; Olson and Olson, 2013). These works mainly highlight the difficulties in exchanging non-verbal bodily cues during conversations for personal and work related settings, for example, in communicating eye gaze, spatial orientation and hand gestures. In response, video callers adjust their verbal conduct to communicate the intended meaning. However, the challenge is significant in clinical settings like physiotherapy, where the focus itself is on improving the patient's body movements. While adjustments through verbal communication can be made, they may not be sufficient for an effective consultation outcome.

Studying video consultations of physiotherapy becomes crucial because physiotherapists are increasingly reliant on video consultations to support their patients at home. In Australia, due to the geographically dispersed population and increasing cases of chronic conditions, delivering physiotherapy services through telehealth platforms is listed as the priority agenda of the Australian Physiotherapy Association (Association and Others, 2013; Australian Physiotherapy Association, 2014). This thesis, therefore, attempts to understand the significance and challenges of bodily communication in video consultations, in order to improve our understanding of the limitations of video technology and to guide new ways to support bodily communication in video consultations. I will investigate video consultations from the physiotherapists' perspective because the success of a clinical consultation depends upon the effective assessment and treatment by the clinicians (Demiris et al., 2010; Fryback and Thornbury, 1991).

1.2. Thesis Statement

Located within the Human-Computer Interaction (HCI) tradition, this thesis investigates the following research question:

> How can interactive technologies support physiotherapists in understanding patient's bodily information during video consultations?

I divide the main research question into three sub-questions with each question forming a separate study. With respect to these three research questions, I carried out three studies that collectively answered the main research question. Below I list the three sub-questions along with a brief description of the respective study.

> RQ1: How do physiotherapists interpret bodily information in the current practice of video consultations?

Given the limited understanding of the role of bodily communication in video consultations of physiotherapy, the design opportunities in the context of video consultations were not clear from the beginning. Therefore, I started my inquiry by conducting an exploratory study of physiotherapy related video consultations to understand the communication of bodily information in the current practices of video consultations in the hospital setting. This study revealed the challenges faced by physiotherapists in understanding the patient's bodily movements and highlighted that lower limb movements are particularly more challenging to assess and treat over video.

Findings of this study guided the development of a research prototype - *SoPhy* that can monitor and present details of patient's lower limb movements to physiotherapists in real-time during video consultations. I developed *SoPhy* because none of the existing devices satisfied the research requirements. (*SoPhy* stands for 'socks for physiotherapy' and is pronounced as 'Sophie')

> RQ2: How does *SoPhy* influence the efficacy of physiotherapists in assessing lower limb movements in (simulated) video consultations?

The second sub-question sets out to evaluate the utility of *SoPhy* in supporting the diagnostic tasks of physiotherapists during video consultations in a laboratory setting. Since *SoPhy* captures information related to lower limb movements, the study focuses on understanding the influence of *SoPhy* in assessing lower limb movements over video.

This phase was essential because, in clinical research, new devices should not be deployed directly at the field (Blandford et al., 2015). Given the sensitivities involved in clinical settings, it is required first to confirm that the developed system has benefits for both the patients and clinicians and that it does not further aggravate the patient's condition.

RQ3:	How does *SoPhy* influence the efficacy of physiotherapists in assessing and treating lower limb movements in hospital video consultations?

After getting confirmation about the potential benefits of *SoPhy* for physiotherapists in the laboratory setting, the final sub-question evaluates the use of *SoPhy* with real physiotherapists and patients in the hospital setting. This field study aims to understand how *SoPhy* helps physiotherapists in assessing and treating patients with lower limb issues during video consultations.

1.3. Thesis Scope

This thesis aims to support physiotherapists in assessing and treating patients during video consultations by providing them essential bodily information related to patient's movements. This thesis answers the research question within the following scope:

1. This thesis only investigates the synchronous form of video consultations. Remote consultations can be organised using different platforms like video technology, emails, discussion forums, SMS and telephones, and can follow two types of communication: synchronous and asynchronous. An asynchronous communication is an exchange of information between the clinician and patient happen at different times, e.g., through email exchange. However, this thesis only focuses on synchronous communication, i.e., real-time communication between clinicians and patients through audio and video medium.

2. Secondly, video consultations studied in the thesis are limited to two-site communication between a physiotherapist and a patient. To this end, the other possibilities of video consultations such as consultations between two clinicians (experts), and consultations involving more than two sites (e.g., a GP at the third site) are excluded from the research investigation. Similarly, video consultations observed to conduct this research did not involve nurses or GP on the patient side. However, the sessions included in this thesis involved other participants such as family members on the patient side and other clinicians at the physiotherapist end.

3. Finally, this thesis mainly investigates physiotherapists' perspective on video consultations. While the thesis does not focus on improving the patients' health outcomes, providing clinicians with better information for conducting diagnosis and treatment may lead to improved health outcomes.

1.4. Thesis Outline

The thesis is organised in the following way (refer Figure 1-1): Chapter 2 presents a review of the literature relevant to this thesis. It starts by providing an overview of the related works on video consultations and then illustrates the importance of bodily communication in face-to-face clinical consultations. The chapter then outlines the limited understanding of the role of bodily communication in video consultations and borrows the literature from video-mediated communication in the non-clinical setting to articulate the research gaps. Chapter 3 describes the research design followed in the thesis. The chapter starts by providing a summary of the different methodologies and methods used throughout the thesis. It then lays out the design of each study and justifies the choice of methods used to collect and analyse data with regards to the research questions.

Chapter 4, 6 and 7 present details of the three studies conducted to answer three research sub-questions (listed in Section 1.2). Each chapter provides details on the methodology chosen to conduct the study, findings gathered from the study and a discussion on how the research questions were answered. Chapter 5 illustrates the development of a research prototype, *SoPhy*, with details of different iterations of the *SoPhy* socks and web-interface. Finally, Chapter 8 concludes the thesis by providing a discussion on the three studies and summarizes how each study contributed to answering the main research question of the thesis. It lists out the research contributions made by the thesis and offers design considerations to motivate the design of future video consultation systems. The chapter also provides directions for conducting future research in the area of video consultations, while considering different challenges of the context.

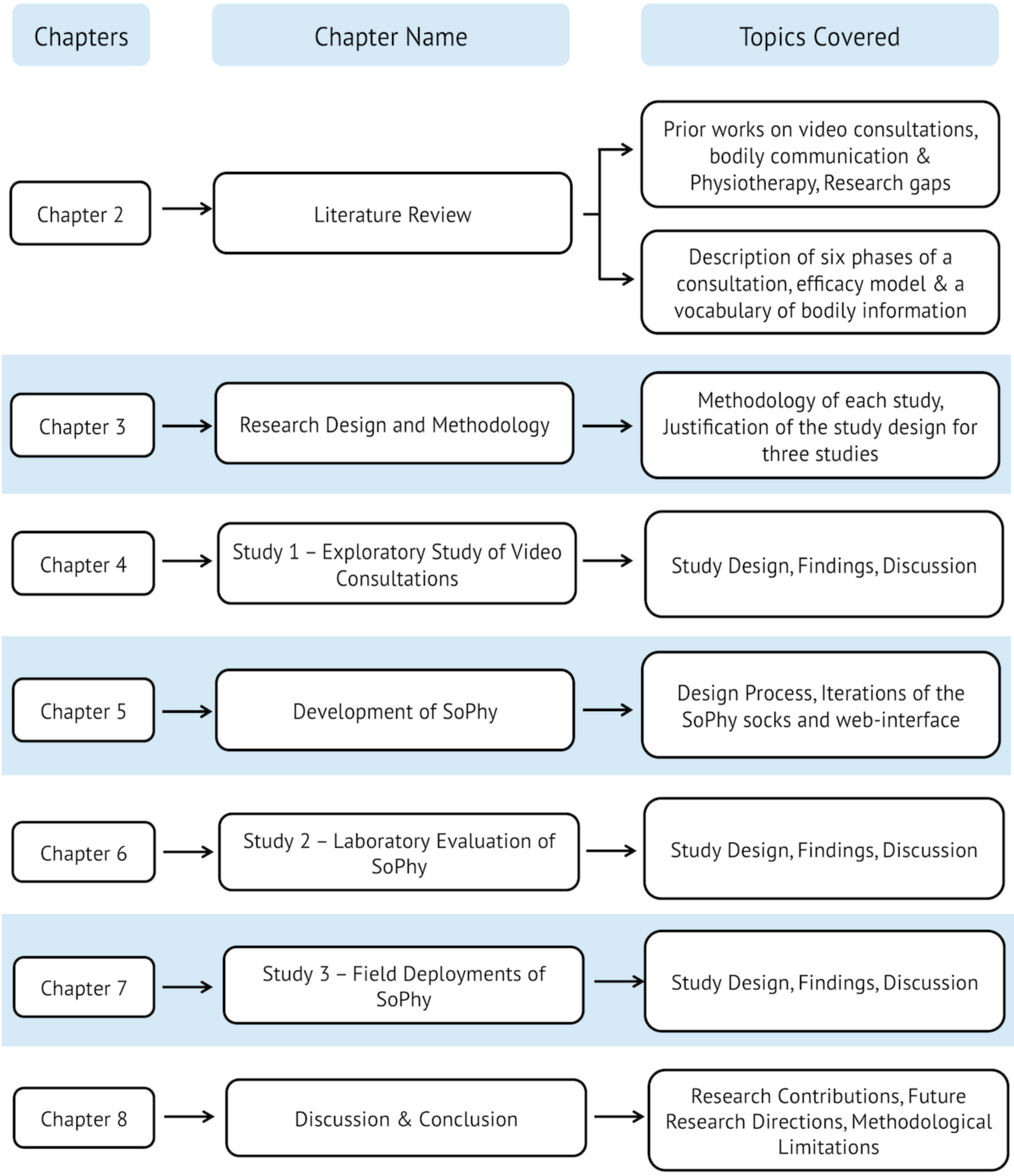

Figure 1-1: Thesis outline.

Chapter 2
Literature Review

Overview: This chapter presents the existing works around three related topics, namely, video consultations, bodily communication, and physiotherapy. Through the critical analysis of the existing literature, the chapter highlights the research gaps that guided the conduct of this research.

2.1. Introduction

In this chapter, I will review the existing works relevant to this research and will discuss the research gaps that guided me to investigate the area of video consultations further. Since this research investigates the significance of bodily communication in video consultations of physiotherapy, I will present the related works around three overlapping topics: video consultations, bodily communication, and physiotherapy (refer to Figure 2-1). Also, since video consultation is a form of clinical consultation mediated through video conferencing tools, this research also draws some concepts from the literature on face-to-face consultations and video-mediated communication for non-clinical settings.

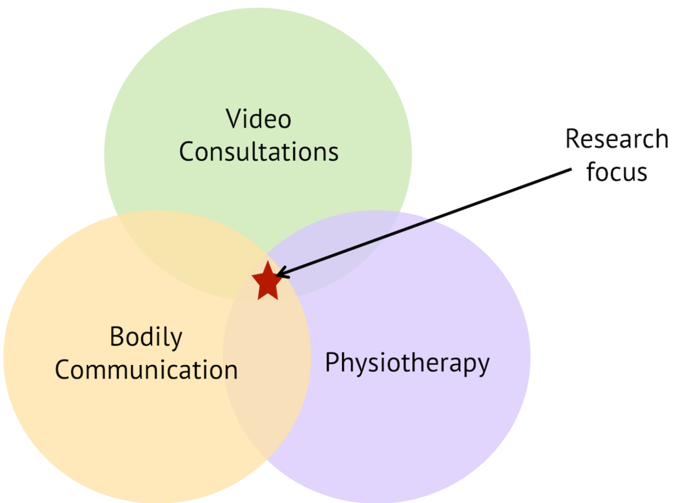

Figure 2-1: This research lies at the intersection of three areas: video consultations, bodily communication, and physiotherapy.

The chapter is structured around the three topics shown in Figure 2-1. Section 2.2 provides an overview of the advancements made in the area of video consultations. It also describes the phases of clinical consultation and an efficacy model to evaluate a new tool in the clinical setting. Although the phases and the model are defined for the face-to-face consultations, they are adopted in this thesis to investigate video consultations. Section 2.3 describes the concept of bodily communication and different types of bodily information that we exchange through our body. The section also describes the relevant literature on the face-to-face consultations, video-mediated communication and video consultations around bodily communication. Section 2.4 explains the clinical practice of the physiotherapists and the technological advancements around supporting physical rehabilitation. It also establishes a list of bodily information relevant for physiotherapy consultations that I will utilise later in the thesis to describe the activities of the patients and physiotherapists during video consultations. Based on the review of these works, Section 2.5 lists out three research gaps that guided this research and presents an overview of how outlined studies address these gaps. Finally, the chapter is concluded in Section 2.6.

2.2. Video Consultations

Over the last two decades, video consultations have become a popular approach to serve the needs of the patients living in remote and rural areas or those having mobility issues. Video consultation is an emerging form of clinical consultations, where distantly located clinicians and patients utilize video conferencing tools like Skype for diagnostic or therapeutic advice (van Dyk, 2014; Yellowlees, 2005). Video consultations fall under the umbrella term of telehealth, where the aim is to support patients with the essential health services over-a-distance. Telehealth covers a wide variety of communication platforms supporting both synchronous and asynchronous communication between the patients and clinicians (e.g., online forums, telephonic conversations, email conversations, and video consultations). Video consultation is one specific form of telehealth that supports synchronous communication between the patients and clinicians.

Video consultations can follow different arrangements (Ekeland et al., 2010; van Dyk, 2014). For instance, video consultations can be organised between the patient and clinician to assess and diagnose the patient over-a-distance. The patient is typically accompanied by their carers or family members. Besides, patients can also be accompanied by other clinicians such as a GP, nurse or other experts, who act as a proxy for the remote clinician to perform the necessary assessment and treatment (e.g., (Larsen and Bardram, 2008; Stevenson, 2010)). Additionally, video consultations can also be organised between two experts to discuss a patient's case (e.g., (Mentis et al., 2016a)). Finally, video consultations can also be organised for educational purposes such as educating the patient or their carers about the underlying health issue (e.g., (Aggarwal et al., 2015)). This thesis only investigates the communication between the patients and clinicians during video consultations when the patient is not accompanied by a proxy clinician. However, given the lack of the literature around video consultations of physiotherapy, I have also taken inspiration from the works investigating other settings of video consultations. Additionally, this thesis investigates video consultations from the clinician's perspective. Hence, the models adopted from the existing literature focus on the activities of the clinicians.

Video consultation is becoming a viable clinical practice because of the numerous benefits that it offers to both the patients and clinicians (Demiris et al., 2010; Dods et al., 2012b; Miller, 2001). For patients, video consultations save office hours, transportation cost and other miscellaneous costs of food and accommodation not only for the patients but also for their carers, by delivering services directly at home. For clinicians, video consultations provide an opportunity to expand their care and knowledge beyond the four walls of their hospital. It improves the efficiency and productivity of the clinicians by accessing persistent knowledge about their patients with the reduced cost of maintaining the clinical conditions at hospitals (in terms of bed quality and clinical staff). Video consultations also allow an easy way to connect patients with a multidisciplinary team of clinicians living across different parts of the world (Zhu and Cahan, 2016). Furthermore, Dorsey and Topol appreciated video consultations as a traditional way of care by noting that, *"the standard for patient-centered care is not a clinic appointment in which patients come to see their physicians in their clinical environments but rather a house call, in which physicians come to see patients in their home"* (Dorsey and Topol, 2016, p. 158).

The existing literature, however, does not provide details as to how clinicians and patients interact during video consultations and how a video consultation progresses to allow different types of activities between patients and clinicians. In order to understand the clinician-patient interactions during video consultations, I will draw the structure of a clinical consultation (Byrne and Long, 1976) from the established literature on face-to-face consultations. The structure of a clinical consultation will help me to understand whether and how the current systems for video consultations fulfill the varying needs of the remote physiotherapists and patients, and the associated challenges. I will also utilise this understanding to review the literature on bodily communication. Next, I will describe the structure of a clinical consultation.

2.2.1. Phases of Clinical Consultations

A clinical consultation is an encounter between the patient and clinician, where the discussion revolves around improving or managing the patient's condition (Heath, 1986).

These consultations involve tightly organised activities such as gathering information about the patient's health, assessing their condition and suggesting treatment plans. Byrne and Long (Byrne and Long, 1976) provided a structured approach to understand the clinician-patient interactions during a consultation. They defined that a consultation progresses across six phases: Opening, History Taking, Examination, Diagnosis, Treatment, and Closing. Each phase has a specific aim that requires different interactions between the patients and clinicians. The authors also described that the consultations do not strictly follow the same order of phases, and different phases may happen at different times during the consultation or may be intertwined at times. In this regard, it is the aim and the clinician-patient activities that differentiate these phases and not their sequence. The proposed structure is based on the institutional asymmetry (ten Have, 1991) that clinical consultations follow, where the clinicians hold higher authority and more responsibilities than the patients. In this regard, the phases are described from the clinician's perspective, illustrating that clinicians are responsible for progressing the consultation from one phase to another as well as to accomplish the overall agenda.

Below I describe the structure of a clinical consultation around six phases, as described by Byrne and Long (Byrne and Long, 1976).

1. *Opening* – The consultation begins with the Opening phase. During this phase, the clinician aims to build a rapport with the patient and attempts to relate to their health issue through informal conversations.

2. *History Taking* – After establishing a rapport with the patient, the clinician seeks to discover the reason for the patient's attendance in this phase. Clinicians ask different questions from the patient about the existing health issue. Patients put forward their complaints, and also update the clinicians about any improvement from the ongoing treatment.

3. *Examination* – The consultation then advances to the Examination phase, where the clinician conducts a verbal or physical examination (or both) of the patient to understand the underlying health issue.

4. *Diagnosis* – Based on the performed examination, the clinician then describes the underlying issue to the patient by using established medical information. The clinician also describes the potential causes, symptoms and effects of the disease.

5. *Treatment* – In this phase, the clinician suggests a medication or therapy to the patient to recover from (or manage) the given health issue.

6. *Ending* – Finally, the clinician terminates the consultation through small talk and schedules another appointment, if required.

These phases have been utilised in previous works to understand how the clinician-patient interactions emerge over time and how these interactions are different in different settings. For example, understanding the interactions when either or both patients and clinicians are non-native English speakers residing in an English speaking country (Bagheri et al., 2014; Cegala, 1997; Meeuwesen et al., 2007). Findings of these studies highlight the need to provide appropriate communication training to the clinicians. Taking inspiration from these works, I will employ these phases in this thesis to understand the interactions between the patients and physiotherapists in the current practices of video consultations, and to identify ways to support their communication better.

Although these phases were defined when face-to-face consultations were the norm for clinical consultations, they are equally relevant in video consultations because the aim of a clinical consultation will remain the same, i.e., to assess and treat patients, whether the consultation is organised in a collocated or remote setting. However, the way to achieve these aims may differ because of the different affordances of the communication medium, which I will investigate in this thesis (in Study 1). After knowing the different tasks and the flow of clinical consultation, I will now look at how the video consultation systems have advanced to support these clinician-patient interactions. In the next section, I will review the existing systems for video consultations.

2.2.2. State-of-the-Art Video Consultation Systems

There is a large body of research on video consultations in clinical domain with a significant focus on exploring the feasibility of organising video consultations for a wide range of health issues, e.g., mental health disorders, diabetes, skin issues, alcohol abuse, stroke rehabilitation and cardiovascular diseases (Dorsey and Topol, 2016; Ekeland et al., 2010; Miller, 2011, 2003). While doing so, the underlying assumption, however, has been that if the given technology worked for supporting one health intervention, it would work for another health intervention as well. Consequently, the video consultations are majorly limited to the use of audio-visual stream supported by video conferencing tools. As yet, the technological advancements in such systems have been the shift from the desktop computers to mobile devices (e.g., laptops), increase in the network bandwidth to allow better quality of video and audio streaming along with certain variations in the setup, e.g., using a combination of telephone, television, portable cameras and screens for different consultations (ibid.).

On the other hand, the interest in video consultations within the HCI domain grew only in the last couple of years (Fitzpatrick and Ellingsen, 2013). So far, the potential of video consultations include the following works: supporting post-surgery consultations between the patients and surgeons (Stevenson, 2010), surgeon to surgeon communication for organ transplantation (Mentis et al., 2016a), autism-related parent training by a speech therapist (Aggarwal et al., 2015), and supporting consultations for senior patients having foot ulcers (Larsen and Bardram, 2008). Researchers are also making different attempts to raise awareness and motivation to advance the field of video consultations further. For instance, Chen and colleagues (Chen et al., 2013) organised a workshop at CHI 2013 on "Is my doctor listening to me," where they discussed the opportunities to design interactive technologies for supporting both the collocated and remote interactions between the clinicians and patients. While these efforts suggest the growing interest on understanding the interactions during video consultations, no investigation has been made to understand how to offer physiotherapy care to the remote patients over video. Like the clinical domain, the technological advancements in HCI also remain on supporting the audio-visual connection between the patients and clinicians, with the use of devices like pen-tablet systems (Stevenson, 2010), mobile phones (Larsen and Bardram, 2008), and more recently Google Glasses to allow real-time manipulation of images (Mentis et al., 2016a).

As such, the focus so far has been on establishing the audio-visual communication link between the patients and clinicians during video consultations with some attempts at supporting the collaborative tasks between remote clinicians. However, little attempts are made to support and enhance the abilities of the clinicians during video consultations when they are solely responsible for conducting all the clinical tasks over-a-distance. The limitations of the video technology in supporting the clinical tasks are known to the researchers, because of which, the majority of the studies involved an assistant (nurse or GP) at the patient end. For instance, Stevenson (Stevenson, 2010) described having a surgeon at the patient side who conducted the assessment of the patient's surgery wounds. Similarly, Larsen and Bardram (Larsen and Bardram, 2008) described having a nurse at the patient end who assessed the recovery of the patient's foot ulcers. These assistants mainly followed the instructions provided by the remote expert and updated the clinician with their assessment. Having a proxy clinician raises the issue of competence, where the clinicians at both ends have different skill sets which may influence the overall assessment of the patient's condition (Larsen and Bardram, 2008). While on the other hand, it also contradicts the fundamental purpose of the video consultations, i.e., to support patients when they do not have easy access to the health care services.

Clinical researchers have argued that the same technology for video consultations may not work for all health issues (Demiris et al., 2010; Dods et al., 2012a; Miller, 2011). For instance, Dods and colleagues (Dods et al., 2012a) described that clinicians need different information for different health issues. They underlined that the audio-visual medium might work for domains like dermatology, where the health conditions are visible on the body. However, for domains like psychiatry, it may not suffice the needs of the clinicians, as they need to observe the real-time bodily reactions of the patients to conduct their assessment. This thesis investigates yet another health domain -

Physiotherapy, where bodily interactions play a key role. It is, however not yet known how the audio-visual connection during video consultations will support the interactions between the patients and physiotherapists - which this thesis investigates.

Bodily interactions and bodily information play a critical role in clinical settings. However, before describing the importance of bodily communication, I will first describe the parameters that define the success of a video consultation. Knowledge of these parameters will help in understanding the research gaps in the existing literature on video consultations around bodily communication. To this end, the next section describes the measures followed by different researchers in the existing literature to evaluate the success of a video consultation.

2.2.3. Measures to Evaluate Video Consultation Systems

Evaluating a new system is essential to understand its impact on the target population and is more critical in the clinical setting, to understand if the proposed system should be introduced in the clinical practice or not. To achieve so, researchers in both the clinical and HCI domains have utilised different methods and measures to evaluate the use of video consultations systems. In the clinical domain, randomised controlled trials are the gold standard to investigate a new technology or intervention against the conventional mode of treatment (Friedman and Wyatt, 1997). Randomised controlled trials include two groups of participants, where one group receive treatment as per the new intervention and the other (control) group receives the traditional form of treatment. The comparison of the outcome of these groups highlights the success of the new intervention.

Following the randomised controlled trials approach, the clinical researchers have compared video consultations against face-to-face consultations around different factors to understand the feasibility and implications of the video consultations, particularly on the patients. The typical line of investigation has been around the following three dimensions: (1) clinical outcomes measured in terms of the changes in communication pattern and length of stay at the hospital; (2) economic benefits measured in terms of the cost avoidance, cost saving and added cost; and (3) user satisfaction measured in terms of the comfort, ease of use, perceived privacy and technical functionality of the underlying video consultation systems (AlDossary et al., 2017; Demiris et al., 2005; Ekeland et al., 2010; Mennicken et al., 2011; Miller, 2011, 2003). Also, in order to investigate these dimensions, clinical researchers have majorly employed quantitative methods and measures like pre- and post-session surveys and questionnaires, and have conducted conversation analysis to quantify the communication patterns of the participants present in the consultation (e.g., patients, clinicians, carers and other assistants).

Such a quantitative approach to video consultations, however, has raised several concerns. For instance, MacFarlane and colleagues (MacFarlane et al., 2002) argued against the use of the randomised controlled trials and emphasized the benefits of using qualitative methods. They described that the randomised controlled trials could only determine if an intervention worked for the predefined criteria. However, it cannot explain why or how an intervention succeeded or failed, which is possible only through qualitative inquiry. Miller (Miller, 2011) similarly, underlined the need to generate a more detailed understanding of the clinician-patient interactions during video consultations. He described that the post-session surveys and interactions analysis of the participants' communication behavior does not provide sufficient details of their activities performed during video consultations. Understanding of these activities is critical to know if the consultation goals are fulfilled across different phases of a consultation (as seen in Section 2.2.1).

Additionally, a large body of research in the clinical domain is centered around the patient care and access to the healthcare services. In doing so, little focus is given on understanding the clinicians' needs to assess and treat patients during video consultations (Edison et al., 2013; Miller, 2011) - which is contradictory given the importance of accurate examination in the clinical setting (Demiris et al., 2010; Dorsey and Topol, 2016). The limited focus on understanding the clinician's perspective is possibly because the majority of the papers are written by the clinicians, where they have described their personal experience of organising video consultations for their clients. Due to the same reason, studies that investigate the influence of video consultations on the clinician's ability (Hersh et al., 2002; Nelson and Palsbo, 2006; Russell et al., 2011), do not provide details of the clinical procedure followed by the clinicians. For instance, Nelson and Palsbo (Nelson and Palsbo, 2006) conducted a study across five clinical domains to investigate the diagnostic equivalence of clinicians over video. The authors reported that the clinicians were able to perform a similar diagnosis in both forms of consultations when measured around a standard set of clinical measures. However, details of diagnosis over video and what measures were used to evaluate the success of the consultations are not described.

Clinical researchers have raised concerns with how the research in the area of video consultations is approached. Whitten and Love (Whitten and Love, 2005) questioned the high satisfaction of the patients and clinicians reported in the majority of the studies and emphasized the need to generate an accurate picture of the use of video consultations. Miller (Miller, 2011) further described that there is a high degree of uncertainty about what factors work for the clinicians and patients, and what is the relationship between different factors that have influenced the acceptance of video consultations (ibid.). Because of this partial understanding, video consultations are still in a trial phase despite a large body of research from its inception (AlDossary et al., 2017; Miller, 2011; Whitten and Love, 2005). As a result, researchers have underlined the need to follow rigorous study design and evaluation methodology in order to improve the credibility of the intervention (AlDossary et al., 2017; Miller, 2011, 2003). Whitten and Love (Whitten and Love, 2005) emphasized the need to use standardized metrics in order to generate an accurate picture of the setting. On the other hand, Miller (Miller, 2003) asked to combine both qualitative and quantitative methods to make strong connections between different factors.

In HCI, researchers have mainly utilised qualitative methods to generate a detailed account of the activities of the patients and clinicians during video consultations. For instance, Mentis and colleagues (Mentis et al., 2016a) utilised video recordings and interviews to collect rich understanding of how remote surgeons constructed a shared understanding of the patient's organ undergoing transplantation over video. On the other hand, Stevenson (Stevenson, 2010) utilised both the qualitative and quantitative methods (e.g., observations, video recordings of the session, interviews, and questionnaires) to understand the experiences of the patients and surgeons with the video consultation systems. These works describe that the video consultations were successful; however, they do not describe the parameters that defined the success of the conducted assessment and treatment during video consultation.

Lee and colleagues (Lee et al., 2015) took a step forward and presented a conceptual model to evaluate the effect of distance on the decision-making ability of the clinicians during video consultations. They defined three levels of distance - *Construal, Experiential* and *Relational*, to help researchers decide if the clinicians will make risky decisions about the patient's health during video consultations. Here, Construal distance refers to the psychological distance that remote callers feel when they are not present together in the same setting. The level of Construal distance may be less if the remote callers are geographically close to each other. The second distance is the Experiential distance that is created by the mediating technology through its functionality. The remote callers may feel less level of Experiential distance if the underlying technology provides an immersive and engaging environment. Finally, the Relational distance refers to the relational connection between the remote callers developed as a result of the video calling. The relational distance is also dependent upon the mediating technology, and the relational connection will be less if the remote callers are not able to converse openly. The model was evaluated in the lab setting by simulating video consultations with healthy participants (who acted as patients and clinicians).

The model proposed by Lee and colleagues (ibid.) only considers distance to decide the risk involved in making clinical decisions over video; hence it seems more appropriate to verify if a video consultation link should be established between a given geographically dislocated patient and clinician pair. It might also be suitable in settings when the participants of video consultations are not familiar to each other and are meeting for the first time over video, which in itself is not considered as an appropriate approach to organise video consultations (Dorsey and Topol, 2016). However, the model is not suitable to investigate the real-time interactions between the patients and clinicians during video consultations. For instance, the model does not provide a way to understand the clinician-patient interactions at different times in a video consultation.

In summary, the works mentioned above motivate to generate a detailed understanding of the interactions between the patients and clinicians during video consultations. These works although have utilised different methods and proposed different models to understand the clinician-patient activities, none of them evaluated whether the observed video consultation was successful. For a successful consultation, the patients and clinicians should be able to perform their tasks in different phases of a consultation (as seen in Section 2.2.1). For instance, the patients should be able to illustrate their symptoms, whereas the clinicians should be able to assess the patient's condition appropriately. Demiris and colleagues (Demiris et al., 2010) highlighted that the success of a consultation depends upon how well the clinicians are able to perform their assessment. While others described that a successful consultation always involves a good patient-clinician relationship, and meet the requirements of quality of examination and patient care by the clinicians (Dorsey and Topol, 2016). However, the literature does not discuss the specific parameters on which the success of a video consultation can be evaluated.

Since the communication in a video consultation is mediated through technology, the technology plays a key role in defining the success of a video consultation. Hence, it is essential to investigate if the technology used for video consultations support the clinician-patient interactions and if the clinicians can perform the essential assessment. To this end, I will utilise an efficacy model (Fryback and Thornbury, 1991) that describes different parameters to evaluate the efficacy of the designed technology with respect to different clinical tasks of a consultation. The model is although defined to evaluate the efficacy of the imaging systems in a face-to-face setting, but the authors suggested that it can also be utilised in other clinical settings with modifications. I will first describe the parameters of the model in the next section, and then in Section 2.2.5, I will describe the alterations made to make the model applicable in video consultation settings.

2.2.4. Evaluating the Efficacy of New Systems

Any new technology installed in the clinical setting aims to improve the health outcome of the patients, either by directly supporting the patients or by supporting the clinicians. Given the long-term trajectory of the health outcomes, it is challenging to evaluate the influence of a new system on the patient's health. Instead what is more feasible is to evaluate the impact of the proposed system on the decision-making ability of the clinicians. For instance, a system is helpful if it *"changes the differential diagnosis, strengthens an existing hypothesis or simply reassures the clinician"* (Fryback and

Thornbury, 1991, p. 91). Consequently, different efficacy and effectiveness measures are used to rigorously understand how a developed system helps the clinician in making their decisions and how it supports the treatment of the patients.

The term efficacy overlaps with the term effectiveness in a great deal with mainly one key difference, as highlighted by (Kim, 2013). According to the author, efficacy looks at the influence of a system in a clinical setting through clinical trials or laboratory studies, with the aim to explain the phenomenon of a given context. Whereas, effectiveness demonstrates how well a treatment works in real-life conditions with a significant focus on the patient's outcome. For this thesis, efficacy is more appropriate than effectiveness because the thesis is focused on understanding and better supporting the tasks of the physiotherapists during video consultations (i.e., the phenomenon). In this regard, the patient outcome is the side effect that will emerge by supporting the physiotherapists, and not the main focus of this research.

One model that is mainly of interest to this thesis is the efficacy model proposed by Fryback and Thornbury (Fryback and Thornbury, 1991). The model is designed to evaluate the efficacy of a medical imaging system in radiology context. It is a highly cited model in the clinical literature and has been used in different contexts. The model consists of six levels: technical efficacy, diagnostic accuracy efficacy, diagnostic thinking efficacy, therapeutic efficacy, patient outcome efficacy, and societal benefits. In this way, the model incorporates all the essential actors of a clinical consultation such as clinicians, patients, and technology, and defines different aspects that influence the diagnosis of the patient's health condition and the following treatment. The authors defined this model as a hierarchical model to emphasize that a system can be efficacious at the societal level if it is efficacious at lower levels. The hierarchy starts with the technology, and the authors emphasize that the technology in itself should be effective in order to help the clinicians in their diagnostic and therapeutic tasks. The model places the diagnostic efficacy before the therapeutic efficacy, which suggests that the system should first enhance the clinician's ability to assess the patients in order to enhance their ability to treat them. Increased therapeutic efficacy of the clinicians consequently influences the patient's outcome.

Although the model is designed to evaluate the efficacy of the medical imaging systems, I chose this model for this thesis because of the following reasons:

a. Firstly, the six aspects of the model provide a holistic approach to evaluate a new system around all key activities of a clinical consultation (e.g., assessment and treatment) by considering all the stakeholders, i.e., patients, clinicians, and society.

b. Secondly, this model overlaps with the six phases of a clinical consultation (described in Section 2.2.1), as both of them focus on supporting the patient's assessment and treatment from the clinician's perspective. This overlap makes it easier to use both the concepts together. For instance, on one hand, the phases illustrate the different aims of the clinicians and provide a structured approach to understand how a consultation unfolds at different times. The efficacy model, on the other hand, provides specific parameters to investigate the influence of the designed prototype in supporting the clinicians' tasks.

c. Thirdly, since the model is defined around the key activities of a clinical consultation, it provides sufficient flexibility to evaluate new systems in other clinical settings. Additionally, the authors do not strictly specify the methods to use this model, therefore, giving sufficient room to utilise methods appropriate for a given project. (I will describe the methods used in this thesis in Chapter 3.)

Below I describe the different aspects of the model, as described by the authors (Fryback and Thornbury, 1991). Since the model is described to evaluate the medical imaging systems, I adopted it to make it suitable for physiotherapy related consultations. In this regard, the parameters illustrating the proposed six aspects are redefined to illustrate the clinical process of physiotherapists. Table 2-1 presents a summary of the efficacy model and their parameters.

1. *Technical efficacy:* The first aspect of the efficacy model is the technical efficacy that is concerned with the physical parameters of the developed system. These parameters include the functions and information provided by the developed system related to the patient's condition, e.g., a web interface providing details of the patient's history. Technical efficacy of a system is investigated by understanding how different functionalities of the system were helpful for clinicians throughout the consultation.

2. *Diagnostic accuracy efficacy:* The second aspect illustrates the impact of the system on the diagnostic ability of the clinicians such that the new system improves the clinician's accuracy to assess the patient's condition. The authors described it as a joint function of the system and the clinician because finding out the incorrect or abnormal behavior of the patients cannot be solely one by the system but is also dependent upon the expertise of the clinicians. Diagnostic accuracy of a system can be understood by looking at the instances of correction in assessing the patients due to use of the system. Since it's challenging to evaluate the diagnostic accuracy of clinicians, the accuracy is typically self-reported by the clinicians.

3. *Diagnostic thinking efficacy:* This aspect illustrates the impact of the system on the diagnostic thinking of the clinicians such that the clinicians feel empowered receiving the information from the system, e.g., whether the system has strengthened the existing hypothesis, or suggested a different diagnosis.

#	Aspects of the efficacy model	Parameters of each aspect
1	Technical efficacy	a. Different functions of the developed system, e.g., a web-interface
2	Diagnostic accuracy efficacy	a. Instances of correction in the assessment
3	Diagnostic thinking efficacy	a. Understanding of the patient's health issue b. Influence on confidence in assessing the patient c. Ability to assess patients (e.g., exercises)
4	Therapeutic efficacy	a. Changes in the treatment choices b. Influence on the clinician-patient communication pattern c. Ability to try different treatment plans (e.g., exercises) with the patients
5	Patient outcome efficacy	a. Ability to describe symptoms b. Understanding of own health issues c. Ability to try the recommended treatment (e.g., different exercises)
6	Societal benefits efficacy	Not explored in the thesis

Table 2-1: Different aspects of the efficacy model and their parameters.

Diagnostic thinking efficacy is investigated by understanding how well the clinicians understand the patient's condition through the system, and whether the system increases their diagnostic confidence - measured typically through the self-reports of the clinicians.

4. *Therapeutic efficacy:* Therapeutic efficacy concerns with the impact of the system on the patient's outcome, i.e., whether the system favorably affects the management of the condition. Since the treatment requires participation of both the patients and clinicians, the therapeutic efficacy is described through different parameters like: whether the system supports the clinicians in making certain changes in the treatment, how it influences the communication between the patients and clinicians, and whether it supports the clinicians in trying different treatment plans with the patients.

5. *Patient outcome efficacy:* This aspect concerns with the ultimate goal of the medical care, which is to improve the patient's condition. Understanding the effect of a system on the patient's outcome is, however, challenging especially when the symptoms prevail for long-term such as in chronic conditions. Hence,

the outcome can be measured by understanding how the system helped the patient in describing their symptoms, in trying out the recommended therapy such as different exercises, or in understanding their health issue.

6. *Societal benefits:* This aspect of the model analyzes the costs and benefits of the designed technology beyond individual level to the society level. It is applicable for the policymakers who are responsible for allocating the resources to a large group. For example, the policymakers will decide whether a technology should be implemented across different departments of a hospital, or across different hospitals in a state. However, I will not utilise this aspect in this thesis because the societal benefits cannot be evaluated through a qualitative study with small participant size. The research presented in this thesis is limited to one specific domain, Physiotherapy, and was conducted only in one department of the collaborating hospital. Understanding the societal benefits rather requires a large-scale study with significant quantitative inferences to understand the implications of a system on the relevant group of people.

In summary, this efficacy model describes different parameters that illustrate the influence of new technology on the clinician's ability to assess and treat patients. I will utilise this model in two ways: firstly, to highlight what is missing in the existing literature on video consultations, and secondly to investigate the impact of a new prototype system that I developed in this thesis to support physiotherapists during video consultations (Chapter 5 describes the design of the prototype system). However, in order to use this model in real-time video consultations, it requires certain modifications, which I describe next.

2.2.5. Using the Efficacy Model to Evaluate Video Consultation systems

I will utilise the efficacy model described in Table 2-1 to investigate the impact of new video consultations systems on the physiotherapists. Employing this model in video consultation settings, however, requires certain modifications. The reason being that the model considers all three actors (i.e., clinicians, patients, and technology) of a consultation separately at different levels in a hierarchy. Also, it is not designed to investigate the real-time interactions between the patients and clinicians with and around the designed system. For instance, the model is used to investigate if a newly implemented system is favorable for a specific setting, where all six aspects are evaluated individually. Such an evaluation does not happen during a consultation, and rather it is conducted at the administration level. However, for the research context explored in this thesis, all the actors interact with each other in real-time, and their tasks vary across different phases of a consultation (as seen in Section 2.2.1).

Consequently, different aspects of the model may simultaneously become relevant when the model is employed to understand the real-time interactions during video consultation. For example, the treatment phase may involve both the therapeutic and patient outcome efficacy because when the clinician recommends a treatment such as an exercise, the patient acts on it immediately. Here, the efficacy of the designed system will help (or limit) the patient in achieving their goals. Similarly, the technical efficacy of a system will influence the overall course of consultation and is, therefore applicable across all six phases of a consultation. As a result, I discard the hierarchy in different aspects of the model and incorporates these aspects collectively in different phases of a video consultation. Table 2-2 presents the mapping between the efficacy model and six phases of a consultation.

This mapping was developed after finishing Study 1, as by then I developed a detailed understanding of how the physiotherapists conduct their assessment and treatment across different phases of a consultation. In this regard, parts of this mapping may not be clear with the understanding of the purpose and structure of the phases from Section 2.2.1. For example, the relevance of the Diagnostic thinking of the clinicians in the Opening and Ending Phase, and the role of the Patient outcome in the Ending phase may be unclear. However, this mapping will become explicit after understanding the findings of Study 1 (explained in Chapter 4).

While the mapping between the phases and the clinical model is sufficient to understand how the developed system enhances the clinician's ability across different phases, it does not provide a way to understand the physicality of the interactions between the patients and clinicians during video consultations. For instance, this mapping lacks in investigating questions like what sorts of activities do the patients and physiotherapists perform during video consultations, how are these interactions different from the traditional face-to-face interactions, and what interactions are difficult to perform over video. Hence, I draw on the concept of bodily communication that illustrates how people communicate with each other using different types of nonverbal cues.

2.3. Bodily Communication

I utilised the concept of bodily communication to understand the activities of the physiotherapy related consultations and the interactions between the clinicians and patients during video consultations. Bodily communication, also called as nonverbal communication, is a key element of human social behavior and has been extensively researched in social sciences to understand the human discourse in different contexts (Argyle, 2013; DeVito, 2011; Ekman and Friesen, 1969). Bodily communication refers to the non-verbal signals that one person communicates to influence another person either consciously or unconsciously (Argyle, 2013). Examples of bodily communication include

#	Phases	Relevant aspects of the efficacy model	Aspects applicable across all phases
1	Opening	- Diagnostic thinking efficacy (e.g., Understanding of the patient's health issue)	
2	History Taking	- Diagnostic thinking efficacy (e.g., understanding of the patient's health issue or influence on confidence) - Diagnostic accuracy efficacy (e.g., instances of correction) - Patient Outcome efficacy (e.g., ability to describe symptoms)	
3	Examination	- Diagnostic thinking efficacy (e.g., understanding of the patient's health issue, or influence on confidence) - Diagnostic accuracy efficacy (e.g., instances of correction)	Technical efficacy (Different functions of the developed system)
4	Diagnosis	- Therapeutic efficacy (e.g., influence on the clinician-patient communication pattern) - Patient Outcome efficacy (e.g., understanding of own health issue)	
5	Treatment	- Therapeutic efficacy (e.g., changes in the treatment choices, ability to try different exercises with patients) - Patient outcome efficacy (e.g., understanding of own health issues, or ability to try different exercises)	
6	Ending	- Diagnostic thinking efficacy (e.g., understanding of the patient's health issue) - Patient Outcome efficacy (e.g., ability to describe symptoms)	

Table 2-2: The mapping between the clinical phases and efficacy model: Different aspects of the efficacy model are relevant in different phases of a consultation.

facial expressions, emotional tone of speech and body posture. Argyle (ibid.) described that the nonverbal communication involves both the encoding and decoding of the message, therefore, such communication is successful only when the another person receives the communicated signal.

Our verbal behavior accompanies a variety of nonverbal signals that add more meaning to what is being said, provide feedback on how the verbal behavior is received, and help to synchronise the conversation (Argyle, 2013; Ekman and Friesen, 1969). Devito (DeVito, 2011) described different purposes that these nonverbal signals fulfill in a social gathering. For example, we use nonverbal cues to illustrate our speech, e.g, indicating the size of a box with hand movements, while talking about it. Similarly, we use bodily cues to regulate the flow of a conversation, e.g. continuously nodding the head to encourage the speaker to continue talking. We also show emotions through bodily cues, e.g., smiling consciously to convey satisfaction. While these examples convey a specific meaning to the other person, some nonverbal cues have no direct relationship with the speech and are merely adaptors to satisfy personal needs, e.g., scratching to get relieved of itching.

Argyle (Argyle, 2013) described that the distinction between the verbal and nonverbal communication does not correspond to being vocal or nonvocal, because we can communicate our verbal behavior through gestures (e.g., repetitive left-right movements of the forefinger communicates ‘No’), and nonverbal signals through vocalisations (such as the tone of speech). Additionally, the nonverbal signals can be both visible such as body posture, and invisible such as the tone of speech. Instead it is the purpose that defines the distinction. As such, while the verbal communication defines “what we say”, the nonverbal communication refers to “how we say it” (Argyle, 2013). Mehrabian (Mehrabian, 1971) highlighted the importance of the bodily communication and described that we communicate 7% of any message verbally through words, 38% through vocal elements such as tone and 55% through other non-verbal cues such as facial expressions, gestures and posture.

Although nonverbal signals form a major part of our communication, we give more preference to the verbal communication to understand the intended meaning of the conversation (Argyle, 2013). The reason being that the nonverbal communication is challenging to understand. For instance, we use several bodily cues simultaneously, and all signals may not communicate the same message. Interpretation of these bodily cues depend upon the other person and is highly subjective. Also, it is hard to know which signals are communicated intentionally, and which are not (ibid.). Additionally, our nonverbal communication is affected by various factors such as an individual’s personality, health (sickness), community and culture (Argyle, 2013; Ekman, 2004). Hence, our nonverbal behavior may differ from other people in the social gathering. In this regard, these nonverbal cues are closely intertwined with the verbal conversations and are best understood in the given context.

Bodily communication is not only a crucial element of the social gatherings, but it also plays a significant role in the clinical consultations (Heath, 2002, 1986). In this thesis, I will utilise bodily communication to illustrate the activities of the clinicians and patients during video consultations of physiotherapy. Because of the different aims of the clinical consultations and the asymmetry of roles between the clinicians and patients, bodily signals serve a different purpose in the clinical setting as compared to the social encounters. Although the existing literature on clinical consultations describes the importance of the bodily communication (which I will review later in Section 2.3.2), it does not provide a list of the bodily information that the clinicians and patients typically exchange in a consultation. Consequently, by reviewing the existing literature on bodily communication (Argyle, 2013; DeVito, 2011; Ekman and Friesen, 1969), I have developed a list of the different types of bodily information that are relevant for clinical consultations. I will describe the list in the next section.

2.3.1. Types of Bodily Information

This section describes the list of the bodily information that I developed to illustrate the activities of the clinicians and patients during video consultations. A clinical consultation not only involves verbal conversation between the patients and clinicians, but it also involves different activities related to the patient's assessment and treatment that are mainly conducted through non-verbal bodily information. In order to illustrate these interactions, I developed a list of fifteen types of bodily information - ten of these are adopted from the literature on social encounters (Argyle, 2013; DeVito, 2011; Ekman, 2004; Kendon, 2010), while the remaining five are adapted from the literature on physiotherapy (Attridge, 2008; Ploderer et al., 2016; Tang et al., 2015).

The developed list includes the following bodily information: (1) facial expressions, (2) eye communication, (3) body posture, (4) body movements, (5) spatial arrangement, (6) body orientation, (7) gestures, (8) vocal cues, (9) touch, (10) appearance, (11) characteristics of movements, (12) quality of movements, (13) tactile information, (14) response to touch, and (15) pain characteristics. In this section, I will describe the first ten bodily information, whereas the remaining five bodily information are described in Section 2.4.1.

Since the existing literature offers different descriptions of the above-listed bodily information, I define these bodily cues to have a consistent vocabulary for the thesis. As an example, body postures, movements, orientation, and spatial arrangement are typically categorised together as postural cues or body movements; whereas gestures are described as body movements (Argyle, 2013; DeVito, 2011). However, I categorised them separately because they individually play a significant role in clinical consultations. Additionally, although the spatial arrangement is typically explained through Hall's (Hall, 1966) theory of Proxemics, I utilised Kendon's description of the use of space (Kendon, 2010). The reason being that the four Proxemic distances (i.e., intimate, personal, social and public) mainly consider the geographical distance between two people to define the type of conversation, which, however, does not hold meaning in the clinical setting. For instance, clinicians typically perform the physical examination of the patient by being closer to the patient, which may fall under the intimate and personal geographical space of the patient according to Hall's theory. Instead of the geographical location, the organisation of people in the space (Kendon, 2010) provides a better way to understand the interactions between different entities (both people and technology).

Below I describe the ten types of bodily information, which are adapted from the following sources (Argyle, 2013; DeVito, 2011; Ekman, 2004; Kendon, 2010). Table 2-3 lists these types of bodily information with some examples.

1. *Facial expressions* include the nonverbal messages that we communicate through our face (DeVito, 2011). Facial expressions are examples of affect displays and they communicate a lot about our emotions. These expressions alone sufficiently communicate our emotions as well as the intensity with which the emotion is felt. For example, a constant big smile communicates our satisfaction, a frown face presents the anger or frustration.

2. *Eye communication* refers to the signals we send through our eyes (DeVito, 2011). Our eyes communicate our personal attitude, our interests and relationship with other people. These messages vary depending upon the duration, direction, and quality of the eye movements. For instance, maintaining a constant eye contact while speaking and a lower level of contact while listening shows the dominance of the speaker, whereas the opposite is considered fine for having a normal conversation.

3. *Body posture* refers to the position of different body parts during conversation (Argyle, 2013; DeVito, 2011). Body posture communicates information related to one's attitude and interest in the conversation. For example, leaning forward and looking constantly at the speaker suggests the listener's attention towards the conversation.

4. *Body movements* are the movements of different body parts that illustrate someone's attitude and thought process, or are performed to fulfill a ritual (Argyle, 2013; DeVito, 2011). These movements are performed consciously or unconsciously, and may not always contain specific meaning. For example, walking with the shoulders and back upright describes the self-confidence and enthusiasm of the person. On the other hand, bending the upper torso to greet another person is a ritual.

#	Types of bodily information	Examples illustrating bodily information
1	Facial expressions	Smiling, frowning, eyebrow-raising
2	Eye communication	Gaze, eye contacts, pupil movement
3	Body posture	Leaning forward, sitting with legs crossed
4	Body movements	Walking with shoulders upright, bending the upper torso for greeting
5	Spatial arrangement	Sitting in a circle
6	Body orientation	Standing sideways to another person
7	Gestures	Pointing the finger to show direction, nodding the head to encourage the speaker to talk
8	Vocal cues	High pitch, heavy tone, other vocalisations such as moaning and yawning
9	Touch	Patting, stroking, caressing, hugging
10	Appearance	Height, clothing, hairstyle, skin color

Table 2-3: List of ten bodily information relevant for clinical consultations. The remaining five bodily information are described in Section 2.3.1.

5. *Spatial arrangement* refers to the use of the physical space to communicate our interest and relationship with other people and artefacts. According to the Kendon's f-formations (Kendon, 2010), participants form a shared transactional segment during interactions, which is easily distinguishable from the outer space. The most typical arrangement of a group participating in a joint activity is a rough circular cluster containing 2-5 people. People and artefacts placed within the circle are actively involved in the activity. People standing nearby or far away may suggest their disinterest in the conversation. Members of the group coordinate their arrangement during the conversation to allow new people to join in and the existing participants to leave, such that if one participant changes his/her position, all others adjust themselves accordingly.

6. *Body orientation* describes the direction a person is facing in a social gathering and communicates one's interest on a person or an artefact. Following the Kendon's concept of space organisation (Kendon, 2010), people typically demonstrates four body orientations namely, one-to-one, side-by-side, semi-circular and corner-to-corner (L-shaped). Different bodily orientations afford different types of tasks such as collaborative, competitive and communicative

tasks. For instance, while standing one-to-one suggests that two people are directly involved in the conversation, sitting side-by-side allows working together on a laptop.

7. *Gestures* refer to the motion of body parts to present a concept (e.g., pointing the forefinger towards the computer to show a picture) or to facilitate the social interactions (e.g., nodding the head to encourage the speaker to continue talking) (Argyle, 2013; DeVito, 2011; Ekman, 2004). Gestures may not be accompanied by the speech as they are self-explanatory.

8. *Vocal cues* refer to the vocal but nonverbal dimension of our speech (DeVito, 2011). These nonverbal cues communicate information about our emotions, feelings and attitudes. These messages vary around different parameters that include pitch, rate of speech, loudness, rhythm and other vocalisations like moaning and yelling sounds. For example, increasing the pitch and lowering down the pace suggest that the spoken sentence is important, and using vocal hesitations while talking suggest the speaker's lack of confidence.

9. *Touch* also referred to as bodily contact or haptics, communicates messages about our feelings and intentions, e.g., gently pressing the hand to show our support and empathy (DeVito, 2011). Touch behaviors are also associated with different rituals (e.g., a goodbye kiss) and with specific tasks (e.g., checking someone's forehead for fever). Touch exhibits both positive and negative meaning depending upon the context and other nonverbal cues of the person (such as facial expressions and posture).

10. *Appearance* refers to the message we communicate through our general body appearance and clothing style (DeVito, 2011). We portray ourselves through our dress and overall appearance. These nonverbal cues provide messages about the personal attitude, financial status, and health (e.g., pale skin color). For instance, dressing informally to teach a class suggests that the instructor is friendly and flexible.

I will utilise the above mentioned ten bodily information to illustrate the activities of the patients and physiotherapists during video consultations in Study 1 and 3. While bodily communication is typically accompanied by the speech in a social gathering and plays a secondary role in the verbal communication, it is more important than the verbal communication in clinical settings. This is because often patients themselves are not aware of what is happening with their body, and therefore cannot always describe their condition through words (Mentis et al., 2016b; Rajabiyazdi et al., 2017). On the other hand, the clinicians are trained to understand the patient's conditions through different bodily information. I will describe the importance of bodily communication in the clinical setting in the following section.

2.3.2. Bodily Communication in Face-to-Face Consultations

A large body of the literature highlights the importance of bodily communication for face-to-face consultations (Cousin and Mast, 2014; Heath, 2002, 1986; Heath et al., 2003; Mishler, 1984; Robinson, 1998). These works suggest that both the patients and clinicians exchange a variety of bodily cues throughout a consultation to serve different needs. Mishler (Mishler, 1984) described the communication pattern of the clinicians and patients through two voices '*voice of medicine*' and '*voice of the lifeworld*'. Because of the institutional asymmetry of roles and responsibilities in clinical settings (ten Have, 1991), Mishler illustrated that the clinicians switch between these two voices across different phases to accomplish the consultation aims. For example, clinicians introduce short talk in the Opening phase to establish a rapport with the patient (*voice of the lifeworld*). However, they suppress such socio-cultural discourse in the Examination phase to give more voice to the biomedical discourse (*voice of medicine*).

Bodily communication is critical across all phases of a consultation (Heath, 2002, 1986; Heath et al., 2003; Robinson, 1998). These works illustrated that bodily communication not only enhances the overall communication between a patient and clinician but also helps in gradually succeeding the consultation through different phases. While the patients utilise different bodily cues to articulate their health issue in the consultation, the clinicians keenly observe these bodily signals to understand the underlying health condition. For instance, during the History Taking phase, patients take pauses while describing their symptoms to check if the clinician is following them or not (Heath, 2002, 1986). Additionally, they utilise eye gaze, facial expressions and body posture to communicate their feelings, as many things are difficult to express verbally. When the patients are describing their symptoms, they also interpret different bodily cues of the clinicians to understand their engagement in the conversation. For instance, while the clinician's nod encourages the patient to describe more, their constant eye contact makes patients comfortable in discussing their health issue. Finally, patients also interpret the clinician's body posture and tactile information like touch to develop trust on the clinician and in the overall treatment (ibid.).

On the other hand, clinicians observe a variety of bodily cues to understand the patient's physical and emotional well-being (Heath, 2002, 1986). For instance, the cracking sound in breathing, vibrating gesture near the mouth, and efforts in speaking altogether illustrate the patient's health issue, when the patient is speaking in the History Taking phase. Oudshoorn (Oudshoorn, 2009) further added that the visual bodily cues such as skin color and eyes are great indicators of the patient's condition and can provide even more details than the objective measures like blood pressure. Apart from the physical descriptors, clinicians (e.g., psychiatrist) read the patient's abnormal body posture, pale face, and hesitation in speaking to understand their stress level (Dods et al., 2012a). To further add, correct positioning of the body part is essential to conduct physical examination (Heath, 1986). For instance, the author described that when clinicians use a stethoscope to examine the patient's chest, the chest needs to be at the correct angle, height, and distance to arrive at a correct reading.

The works mentioned above established the importance of the bodily communication to make a consultation effective and to accomplish the consultation outcome. These descriptions became a gold standard way to understand the clinician-patient interactions during a clinical encounter. With the penetration of information and communication technologies in the consultation rooms, researchers utilised the concept of bodily communication as an analytical lens to investigate whether and how the presence of these technologies influenced the expected clinician-patient interactions, as reviewed by (Fitzpatrick and Ellingsen, 2013). The reason being that the emergence of computers raised several concerns of dehumanizing the patient-clinician relationship as the presence of computers may alter the communication and interaction patterns between the patients and clinicians (Frankel et al., 2005; Makoul et al., 2001). For instance, these researchers expressed their fear that constant use of the computers may take significant time and attention of the clinicians, which in turn will reduce the socio-emotional aspect of the clinician-patient relationship.

In this regard, the existing literature presents both positive and negative views on the presence of computing technologies in the consultation rooms. For instance, Greatbatch and colleagues (Greatbatch et al., 1995, 1993) shed early insights on the use of computer systems by the clinicians and illustrated that the presence of computers altered the intended clinician-patient interactions. They found that the patients manage their conversations around the visible and audible aspects of the clinician's use of the computer, e.g., the patients carefully introduced their utterances by hearing the keystrokes of the computer, which implied whether the clinician was making digital notes or not. Additionally, the presence of computers also modified turn-taking between the patients and clinicians. For example, the patients delayed the extension of their turns until the clinician completed a sequence of keystrokes, and clinicians abruptly shifted their conversation based on the tasks they were doing on the system. On the other hand, some studies reveal positive insights on how well the clinicians are managing the use of computers in the consultation room (Chen et al., 2011; Fitzpatrick and Ellingsen, 2013). For instance, Chen and colleagues (Chen et al., 2011) illustrated that the clinicians continually reorient and resituate computers at different times of the consultation to foster the patient engagement and to invite their participation in the decision-making.

While the debate on the influence of computers on the clinician-patient communication is still ongoing, recent works highlighted the importance of computing technologies to understand the patient's recovery particularly for movement-related disorders (Mentis et al., 2016b; Morrison et al., 2016; O'Hara et al., 2016). For instance, Mentis and colleagues (Mentis et al., 2016b) designed a sensor-based system that captures the upper limb movements of the patients with Parkinson's disease and displays the data to the neurologists on a computer screen. They evaluated the system in face-to-face consultations to understand how the system supports the practice of clinicians in assessing and treating patients, and how it supports patients in interpreting their recovery. Through this work, the authors highlighted the challenge of 'seeing' the movements and the subjectivity associated with interpreting the bodily information. They described that seeing the movements, assessing the level of disability, and recommending the treatment are iterative processes and require collective interpretation from the patients, clinicians, and caregivers. Hence, the systems supporting 'seeing' of movements should support *co-interpretation* of movements by all the actors indulged in the care and management of the patient's condition, i.e., patients, clinicians, and caregivers.

The work by Mentis and colleagues (ibid.) illustrated that not all bodily information is easy to "see" even in the face-to-face setting particularly those that are related to movement disorders - like the one investigated in this thesis related to physiotherapy. When understanding the bodily information is challenging in a face-to-face setting, the challenge will become furthermore severe when the consultation moves from collocated setting to video-mediated setting. In the following section, I will present a review of how bodily communication is mediated in the video-mediated setting. Since video-mediated communication emerged from the work and personal settings, I will start by describing the literature on bodily communication in the non-clinical setting and then will describe the literature on video consultations.

2.3.3. Bodily Communication in Video-Mediated Setting

Within HCI, there is a long history of using the concept of bodily communication to understand and support the interactions between the remote callers during video-mediated communication in non-clinical settings. For work-related video conferencing, Olson and Olson described that bodily cues like facial expressions and gestures are essential at the beginning of the video call, as it helps the remote callers to establish a common ground (Olson and Olson, 2000). They described common ground as the knowledge that participants have in common and they are also well aware of this commonality. Using different bodily cues, participants frequently ask back and forth questions to establish a good understanding about each other, and to smoothly progress their conversation. Interestingly, several studies revealed that in comparison with the audio-only modes of interaction, the presence of visual information (visual feed) in video conferencing did not make any significant difference in the outcome (e.g., in decision-making) and in the structure of conversation (e.g., turn-taking) (Olson and Olson, 2000; Sellen, 1995; Short et al., 1976). To this end, Short and colleagues (Short et al., 1976) concluded that the visual information mainly provides the sense of 'social presence' to the remote callers, and is very important to handle situations of conflict.

However, many works also highlight the challenges of working together over-a-distance (Gaver et al., 1993; Heath and Luff, 1992; Olson and Olson, 2013). Many of the difficulties and asymmetries that are described in the early studies mainly address the differences between video and face-to-face communication with regards to eye gaze and spatial orientation (Bly et al., 1993; Gaver et al., 1993; Heath and Luff, 1992; Morikawa and Maesako, 1998). For instance, these works suggest that the video callers miss out certain bodily cues such as hand gestures, eye gaze, and spatial orientation during video conferencing. Additionally, the lack of these cues makes turn taking challenging to perform and thus, the conversations are typically controlled by the dominant speakers (Sellen, 1995).

Due to these challenges related to bodily communication, Olson and Olson (Olson and Olson, 2000) illustrated that video conferencing is suitable to accomplish only moderately to loosely coupled tasks. *Coupling* here refers to the interdependency between the different components of the task at hand. The authors described that video conferencing may not be suitable to conduct tightly coupled tasks where there is the ambiguity of who is doing what. For example, video conferencing is not suitable for having initial brainstorming sessions for designing a new prototype because such meetings involve intense discussions, where the team members contribute different ideas and take up different roles in real-time, such as making sketches of the prototypes, or scribblings of the potential ideas. It is challenging to involve the remote callers in the discussion the way collocated members are participating. The authors described that any tasks where the participants have reached a common ground in terms of their responsibilities are easier to perform over video. For example, co-authoring a paper is feasible if different authors are responsible for different sections. Co-authors of the paper can then discuss the progress of different sections over the video to develop a coherent argument for the paper, but the significant work is performed at the individual end.

On the other hand, Buxton (Buxton, 2009) described that in order to support collaborative tasks over-a-distance, the remote callers should have an understanding of the following three spaces: *people space, task space,* and *reference space*. *People space* refers to space where people express and communicate their intentions through verbal and non-verbal cues like facial expressions and eye gaze. This is where we look at when talking to a person, and the voice comes from this space. *Task space* is where the person performs the work either individually or collaboratively. To support collaboration, the task space needs to be shared. And finally, *reference space* is the space that people utilise to refer to their work through gestures and body movements. This space is typically an overlapping space of the person and task.

Knowing the challenges of video technology in communicating bodily information to support collaborative works over-a-distance, researchers have designed or appropriated different technologies that support the required interactions between the remote callers. Some attempts are made to enhance the understanding of the task space and reference space of the remote callers. For instance, 'Teamworkstation' (Ishii and Miyake, 1991) and 'Clearboard' (Ishii and Kobayashi, 1992) systems provide a shared drawing surface between remote ends to allow collaboration over-a-distance. To support gesturing and pointing to the task space, 'DOVE' supports drawing over the video of the task space (Ou et al., 2003). On the other hand, 'Room2Room' is another system that provides a life-size video of the remote caller through augmented reality (Pejsa et al., 2016). The system creates an illusion as if the remote person is physically present in the local space, and thereby, aiming to enhance the remote callers' understanding of both the verbal and nonverbal communication. This system is designed to support rich conversation between remote ends by mainly mediating the people space.

As video gets increasingly used for activities that go beyond conversation, from intimate gestures like blowing a kiss to cooking together and playing games (Brubaker et al., 2012; Hunter et al., 2014; Neustaedter et al., 2015), bodily communication remains a concern. The limitation of bodily communication over video, however, did not influence the popularity of video communication in everyday context and people continue to video conference with their remote work partners and family members. For example, studies also suggest that the video callers can reasonably adjust their verbal communication to communicate the intended information at the other end (Brubaker et al., 2012; Hunter et al., 2014). It might be because bodily information does not play a key role in both the work and interpersonal communications as they are task-oriented and are focused more on getting connected with the remote partners. However, if the focus of a conversation is someone's body e.g., a patient's health issue, where every information might not be expressed vocally - appropriate communication of the bodily information over video becomes crucial. In the next section, I will review the literature on video consultations around bodily communication.

2.3.4. Bodily Communication in Video Consultations

Given the importance of bodily communication in the clinical setting (as seen in Section 2.3.2), several studies investigated how bodily communication happens during video consultations. The literature highlights both the viewpoints on video consultations, with one set of works highlighting the challenge of communicating certain bodily information over video, and another set of works describing the presence of certain bodily information. Besides, some technological advancements have also happened to enhance the bodily communication between the patients and clinicians during video consultations. In this regard, I will describe the existing works across three subsections: First, studies reporting the absence of bodily information in video consultations;

secondly, studies reporting the presence of bodily information in video consultations; and finally, technological solutions to enhance bodily communication in video consultations.

Studies Reporting the Absence of Bodily Information in Video Consultations

Studies in the clinical domain highlighted that video consultations lack in communicating important non-verbal cues, such as eye contact, head nods, blinks and facial expressions, which are essential for supporting rich conversation between the patients and clinicians (Bulik, 2008; Cukor et al., 1998). Lack of the essential bodily information influenced the communication pattern between the patients and clinicians. For instance, some researchers highlighted that clinicians introduced lesser small talk in video consultations and directly talked about the patient's health issue (Agha et al., 2009; Nelson et al., 2010). They also described that taking turns was also challenging to manage over video. And as a result, the clinicians uttered more words than the patients and held the conversation floor during video consultations. Another study added that the patients only provided information when being asked, and their participation further reduced in the presence of other carers and clinical assistants (Wakefield et al., 2008). Cukor (Cukor et al., 1998) expressed his fear that since much of the conversation happens through audio channel, video consultations may be less effective for the interpersonal communication. Additionally, the lack of interpersonal moments (e.g., through small talk) and social interactions during video consultations are described as potential risks in establishing an empathetic relationship between the clinician and patient (Evans, 1993; Miller, 2003; Storni, 2009).

Miller also highlighted the limitations of multisensory interactions between clinicians and patients during video consultations (Miller, 2003, 2001). He described that video consultations primarily involve the visual and auditory medium, and lack other multi-sensorial outlets such as touch or smell of the patient that the clinicians significantly use in face-to-face consultations. This lack of tactile and multi-sensorial information may influence the clinician's diagnosis and their confidence in the assessment. This limitation of video consultations is evident as some studies also show that the clinicians recommended more tests and referrals to their patients in video consultations than in a face-to-face setting (Bulik, 2008). Additionally, the absence of '*laying on of the hands*' may influence the emotional and psychological bonding between clinicians and patients (Miller, 2003, p. 3). Clinician's touch is not only considered as Placebo to improve the patient's condition (Chaput de Saintonge and Herxheimer, 1994), but is also essential to show empathy to the patients especially in situations when the clinicians need to break bad news (Ptacek and Eberhardt, 1996).

While the above-mentioned works highlight the absence of different bodily information, this understanding is mainly limited to the bodily information required for supporting conversation between the patients and clinicians, with a focus on supporting the patients' needs. These works do not describe whether and how bodily information essential for assessing and treating the patients was mediated over video technology; and how the absence or presence of certain bodily information influenced the ability of clinicians in following their clinical procedures. For instance, whether the clinicians were able to conduct the necessary examination and treatment effectively through different phases, as seen in Section 2.2.1. Although some researchers highlighted that the lack of bodily cues would reduce the clinician's confidence in their assessment (Miller, 2003) and may make the overall assessment less effective (Cukor et al., 1998), these are only anecdotal pieces of evidence or predictions with no detailed studies.

Studies Reporting the Presence of Bodily Information in Video Consultations

Another set of studies suggest that video consultations support important bodily information between the remote participants. In this regard, some studies note that bodily information is equally present in video consultations as in face-to-face consultations, and that the voice of patients is not suppressed in the video consultations. For instance, Demiris and colleagues (Demiris et al., 2005) found that there is no difference in the communication pattern of the clinicians and patients during video and face-to-face consultations. Additionally, Tachakra and Rajani (Tachakra and Rajani, 2002) added that the patients took more turns and uttered more words than their clinicians in video consultations as compared to the face-to-face consultations. They also found that the patients asked more questions during video consultations, and the clinicians took greater care in maintaining the coordination.

Additionally, some studies also illustrate that video consultations provide certain bodily information that may not be directly visible in face-to-face consultations. For instance, McLaren and colleagues (McLaren et al., 1995, 1996) described that the clinicians were able to easily detect certain clinical symptoms such as tongue tremors in video consultations, as video removes all the distractions from the view and allows the clinicians to focus only on the patient. The authors also described that psychiatric patients found it more comforting and less inhibiting to discuss their problems with their psychiatrist over video than in the face-to-face visits (McLaren et al., 1995). Because of the less threatening environment that video consultations offer, Miller (Miller, 2003) speculated that consultations of the stigmatized diseases such as sexually transmitted diseases may be more comforting for patients to discuss over video.

In the similar vein, Aggarwal and colleagues (Aggarwal et al., 2015) also discussed the positive effects of video on the parents, when two parents with Autistic kids were offered remote training by a speech therapist. Their study highlighted that the parents found the video environment less intimidating to raise and discuss issues with their kids. They also felt an increased sense of social presence with the speech therapist as compared to the face-to-face sessions. For instance, since the speech therapist was sitting in front of the parents, i.e., one-to-one position on the video call, the parents felt that they were always heard by the therapist. This is not possible in the traditional face-to-face training sessions, where the room is full of several parents and the therapist has to attend everyone. Additionally, the authors described the strategy of the parents to manage the digital presence of other parents and the speech therapist by managing their VSee[1] windows. For instance, the parents reduced the size of the other parent's window and increased the size of the speech therapist's window to reduce the psychological distance with the therapist. (VSee software creates a separate window for each user and the users can individually manage these windows on their screen.)

While the above-mentioned works utilised the standard video technology with some differences in the configuration (e.g., use of two screens), some studies utilises other interactive technologies along with the video technology to support the required bodily interactions during video consultations. For instance, Stevenson (Stevenson, 2010) carefully designed the setup of the surgery related video consultations by using an array of webcams and a pen-and-tablet system. The author aimed to support rich interactions between the remote ends by creating a media space that provides information related to the three spaces proposed by Buxton (Buxton, 2009): people, task and reference space. These video consultations were organised for the pediatric surgical patients, where the patients were accompanied by a clinical assistant to help in the assessment. Their study highlighted that the use of the pen-and-tablet system enhanced the participant's understanding of the task and reference spaces, which in turn, supported rich discussions between the patient and surgeon during video consultation. For instance, the system helped in mediating the gestures such as annotation of and pointing towards the patient's records during the session, and helped the patients and family to obtain a better understanding of the underlying condition and the treatment trajectory. On the other hand, having multiple camera views helped the participants to be aware of who is sitting where and who is talking to whom, along with a better understanding of each other's attention and eye gaze (understanding of the people and reference spaces). However, the author also highlighted that the presence of multiple cameras made the consultation room daunting for the patients and their family because often patients were required to show off their affected body area to the remote surgeon and having multiple cameras made them hesitant to do so. Consequently, the surgeons handled the sensitive conversations afterward in the follow-up face-to-face sessions with patients - which was feasible as the study was organised across two rooms of the hospital.

Furthermore, Stevenson (ibid.) also utilised high-quality audio and video systems to support clear communication of the patient's nonverbal cues to the remote clinicians during video consultations. He described that the high-quality video helped the remote

[1] VSee software. https://vsee.com

surgeon to understand the subtle bodily cues of the patient that were essential for assessment. For instance, the remote surgeon could observe a slight flinch in the patient's body when the assistant touched the patient's knees to examine. The surgeon then cautioned the assistant to be careful in following the clinical procedure as the patient was very ticklish. The importance of high-quality video and audio channels for organising video consultations is also emphasized by other researchers (Demiris et al., 2005; McLaren et al., 1995; Miller, 2003; Stevenson et al., 2010). Such emphasis on the audio and video quality is in contrast with the literature in non-clinical video-mediated communication. For instance, some studies (Olson and Olson, 2000; Sellen, 1995) showed that the visual information does not add significant value in the overall conversation, and the remote callers mainly rely on the audio channel to communicate.

Similarly, Mentis and colleagues (Mentis et al., 2016a) utilised Google glasses to support collaborative organ transplantation between two remote surgeons through video consultations. They mediated the task space (Buxton, 2009), which is the patient's organ undergoing transplantation, over-a-distance to support the verbal and nonverbal communication around it. During the organ transplantation surgery, the recovery surgeon prepares the patient for transplanting the new organ and performs the necessary operation; whereas the implant surgeon helps in assessing the viability of transplanting the new organ over video. The use of Google Glasses provided the first-hand view of the task-at-hand, i.e., organ undergoing transplantation, and created a better understanding of what the recovery surgeon is looking at and referring to during the conversation (eye gaze). The recovery surgeon could manipulate the view of the camera as needed for the discussion, by controlling the Google glasses through gestures. The authors found that the video streaming through Google Glasses supported the essential bodily information related to eye gaze between the surgeons and hence facilitated the effective co-construction of knowledge and real-time decision-making between the surgeon.

Technological Advancements around Bodily Communication

There have been limited attempts to design technologies that can support rich bodily interactions between the patients and clinicians during video consultations. These advancements include an annotation system designed by Palmer and colleagues (Palmer et al., 2007) that mediates gestures between the remote clinicians in surgery related video consultations. The system was designed to assist the assistant at the patient end in assessing patients when working under the guidance of a remote clinician (expert). The system consists of a pen and tablet-based system with laser projection. During a video consultation, when the clinician annotates a still image of the patient (captured from the video stream) on the tablet using a tablet-pen, the system on the patient end projects these annotations on the patient's body. The clinician on the other end utilises these annotations to decide the next step. Authors evaluated the working of the system through a laboratory study conducted with healthy participants. Another example includes a helmet-based system (Li and Alem, 2013) to mediate gestures between the clinician and patient in video consultations. The helmet has a head-mounted webcam and a near-eye display beneath the brim that can potentially show the video of the patient and gestures of the remote clinician. However, no accompanying laboratory evaluation or field study was conducted to evaluate the system.

In summary, the above-mentioned works illustrate the limitations as well as solutions to overcome certain challenges related to bodily communication during video consultations. These works illustrate that through interactive technologies it is possible to not only mediate the bodily information like gestures and eye gaze essential for supporting verbal communication between the remote callers, but it is also possible to support real-time decision making between the clinicians in critical settings like operation theatres. Taking inspiration from these works, this thesis investigates the potential of the interactive technologies to mediate bodily information over video in yet another domain, Physiotherapy, where bodily communication plays a crucial role. In the next section, I will describe the importance of bodily communication in the clinical practice of physiotherapists and will argue that further investigation is required to support physiotherapists during video consultations.

2.4. Physiotherapy

Physiotherapy is a post-rehabilitation activity that is aimed at improving and restoring the functioning of the patient's body after an injury, surgery or chronic physical impairments (Attridge, 2008). Physiotherapy is crucial in different conditions such as chronic pain disorders, arthritis joint pain, and rehabilitation of dislocated and fractured joints, and is appropriate for people across all ages from young kids to elderly population (Australian Physiotherapy Association, 2014). Physiotherapists prescribe a course of intensive and repetitive exercises or other therapies (such as meditation or education) to help the patient recover. Depending upon the condition, the program lasts for a couple of weeks to months and even years. While the patients are trained with the relevant therapies during these sessions, they are also required to follow them at home with a routine developed by the physiotherapists considering the abilities of the patient. A physiotherapy session is very interactive with the physiotherapist demonstrating and teaching the patient with different exercises, and the patient following them (Dillman and Tang, 2015; Tang et al., 2015). While the patient these exercises, the physiotherapist ensures that the patient is performing these exercises properly by correcting their movements and providing necessary feedback. The assessment and diagnosis of the physiotherapists typically rely on close observations and hands-on work with patients.

Since the overall aim of physiotherapy is to improve the patient's movements, bodily communication plays a key role in physiotherapy consultations (Dillman and Tang, 2015). Not only the patients and physiotherapists exchange different bodily cues to support their conversation as expected in any clinical consultation (as seen in Section 2.3.2); the overall assessment and treatment of the patients happen through bodily communication. In this regard, along with the list of bodily information that I discussed for social encounters, other bodily information also becomes relevant in physiotherapy context. I will describe the relevance of different bodily information in the following section.

2.4.1. Types of Bodily Information Relevant in Physiotherapy Consultations

Interactions during a physiotherapy session happen through a wide variety of bodily information. I will demonstrate the importance of bodily communication through an example. For a lower limb injury, physiotherapists suggest different exercises to the patient. A typical exercise is squat[2] because it reflects on our everyday task, as we squat to pick up things, to wear our shoes, and to go to the bathroom (refer Figure 2-2). Doing squats help the patient to restore the strength and flexibility in their lower limbs particularly around hamstrings. In order to perform squats, the patient is required to consider the following instructions of the physiotherapist: keep the trunk upright, shoulders relaxed and spine in a neutral position, slowly lowering the body keeping the core tight, bear the body weight on the heels, align the knees with the big toe, keep the arms straight and tight, exhale properly, only going to a certain extent, and maintaining the balance while doing certain number of repetitions.

Clearly, the squat is a complex movement, and improper squatting technique may lead to added stress in the back, hip, and knees, and may aggravate pain in these areas. Hence, the physiotherapist makes sure that the patient is following the squats correctly. In this regard, the physiotherapists observe how the patient is appropriating their body while performing the movements because any distortions and appropriations illustrate the patient's condition. For instance, the patient may not breathe properly if the exercise is too painful for them; or the patient may not lower down much if their calf muscles are tight; or the patient may not bear the body weight on heels if the heel area is swollen or painful to touch on the ground. Seeing these appropriations, the physiotherapist may perform a physical examination to check the muscle tightness and swelling in the observed area.

This example illustrates the variety of bodily cues that the patients demonstrate and the physiotherapists observe for just one exercise - squats, without having any verbal

[2] The example of squats is adopted from the following website. https://www.cbphysicaltherapy.com/how-to-perform-a-perfect-squat/

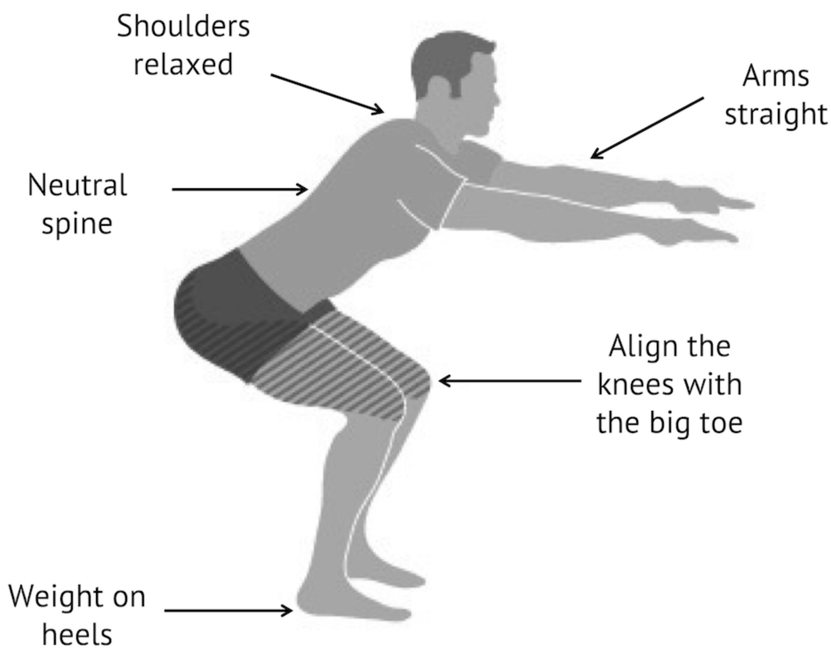

Figure 2-2: A squat is a typical exercise that the physiotherapists prescribe to patients to recover their lower limb strength.

communication. In terms of the bodily information listed in Table 2-3 (Section 2.3.1), a squat is an example of *body movements*, where the physiotherapists check the patient's *body posture* (e.g., position of the back, hip, feet), and perform physical examination by *touching* the affected part. However, the list presented in Table 2-3 does not include bodily information related to the physical assessment of the patient, e.g., tactile information related to swelling and muscle tightness. Nor does the list support describing the details of the patient's movements, for instance, whether the patient dropped down smoothly, or how far the patient dropped down, or whether the patient was able to balance their body while performing squats.

Consequently, I add five more types of bodily information to the list mentioned in Table 2-3. These bodily cues are specific to the information that the physiotherapists require to assess the patients. I defined these bodily cues by reviewing the existing literature on physiotherapy both in the clinical (Attridge, 2008) and HCI domains (Dillman and Tang, 2015; Lam, 2015; Ploderer et al., 2016; Tang et al., 2015), as well as from my personal experience developed through this research (mainly from Study 1). With these five bodily cues, a comprehensive list of bodily information that is relevant for physiotherapy related consultations includes fifteen types of bodily information, which are listed in Table 2-4. I will use this list to describe the clinician-patient interactions later in the study chapters. Below I describe these bodily cues.

1. *Characteristics of movements* are the attributes that define the patient's movements. Our body follows the different degree of movements in different body parts, which are defined through different characteristics (Attridge, 2008). For instance, Tang and colleagues (Tang et al., 2015) described shoulder based exercises through the range of arm movement, movement speed, angles between the joints and extent of the movement.

2. *Quality of movements* describes how well the patient is able to perform the movements. For instance, whether the patient performs the movements smoothly or with a jerk.

3. *Tactile information* refers to the information that the physiotherapists obtain during a physical examination. Examples of tactile information include swelling in the affected body part and tightness in the tissues.

4. *Response to touch* is the reaction of the patient when the physiotherapist touches their affected body part for the examination. For example, the patient could be fearful or may have tickling sensations to touch.

5. *Pain characteristics* are the attributes that describe the patient's pain. Examples include the location of the pain and type of the pain (e.g., pinching pain and throbbing pain).

After understanding the importance of bodily information in physiotherapy consultations, I will now discuss the literature on technological advancements in physical rehabilitation.

Types of bodily information relevant for physiotherapy related consultations		
(1) Facial expressions	(2) Eye communication	(3) Body Posture
(4) Body movements	(5) *Characteristics of movements*	(6) *Quality of movements*
(7) Spatial arrangement	(8) Body orientation	(9) Gestures
(10) Touch	(11) *Tactile information*	(12) *Response to touch*
(13) *Pain characteristics*	(14) Vocal cues	(15) Appearance

Table 2-4: A collective list of fifteen bodily information relevant for physiotherapy consultations. Bodily signals that are specific to physiotherapy are listed in italics.

2.4.2. Technological Advancements for Physiotherapy

Within HCI, there is a significant interest on supporting physical rehabilitation of the patients through interactive technologies. Majority of these investigations aim to support the patients at home during the rehabilitation program or post-program in order to help them in maintaining an active lifestyle in the absence of their physiotherapists. While some technologies provide ways to connect the patients and physiotherapists remotely, none of them is explicitly designed or evaluated to support video consultations of physiotherapy. O'Hara and colleagues (O'Hara et al., 2016) presented a review of the sensing technologies that have been explored to support rehabilitation. In their book, they described that these 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 the patient's movements. Some popular examples of the device used thus far, include the depth-sensing camera technologies like Kinect, sensor-based systems embedded in the surroundings like Wii-Balance board and pressure mats, and body worn sensors embedded with accelerometers and pressure sensors.

Below I will review the existing rehabilitation technologies across two categories: *environmental tracking* and *on-body tracking*. Since there is a significant number of technological solutions for tracking bodily data, I will only review those works that monitor and provide feedback about bodily information listed in Table 2-4. In this regard, systems that are mainly designed to make the rehabilitation process engaging through gamification and scoreboards for example, are not reviewed in this section.

Environmental Tracking

Environmental tracking includes monitoring of the patient's movements using systems that are arranged in the surroundings. Such technologies typically work with automated pose detection and estimation techniques using computer vision based approaches (O'Hara et al., 2016). Commercially available technologies like PlayStation cameras, Microsoft's Kinect and Wii-Fit Board have been commonly utilised to explore the potential of tracking the patient's movements for rehabilitation purposes. These systems although were not developed specifically for the clinical purpose, their low maintenance cost and ease of deployment have made them a popular choice to understand the specifics of body movements (ibid.). Table 2-5 provides the summary of the existing technologies supporting physiotherapy using environmental tracking.

An example of the environmental tracking system is Physio@Home (Tang et al., 2015), a system that is designed to support arm and shoulder rehabilitation of the patients at home. The system captures information related to the range of arm movement, joint

System name	Body Part	Captured bodily information	Sensors used	Purpose
Physio@Home (Tang et al., 2015)	Arm	Range of movement, joint positions and angles, extent of movement, rate of movement	Vicon motion tracking cameras	To support arm rehabilitation at home
OneBody (Hoang et al., 2016)	Full body	Body posture	Microsoft Kinect, Oculus Rift head-mounted display	To support posture guidance in remote training
Nintendo Wii-Fit board	Full body balance	Weight balance	Pressure sensitive surface	To support balance training at home
Stepping tiles (Bongers et al., 2014)	Full body balance	Weight distribution	Pressure sensitive surface	To support balance training at home
Matscan™	Full body balance	Weight distribution	Pressure sensitive surface	To support balance training at home

Table 2-5: Summary of the existing systems using environmental tracking to support the patient's rehabilitation.

positions and angles, extent of movement and rate of movement. The system utilises multiple Vicon motion tracking cameras to capture the required bodily information. Because of the higher precision that Vicon cameras afford, the system highlights the subtle differences in the patient's movements to guide correct movements. The movement data is visualised on a computer screen. 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. This system is particularly of interest to this thesis because this paper unpacks the complexity of movements for arm and shoulder movements to define the characteristics of movements. Their description of body movements helped me to develop the list of bodily information relevant for physiotherapy, as described earlier in Section 2.4.1.

OneBody (Hoang et al., 2016) is another system that utilises Microsoft Kinect and Oculus virtual reality headsets to support remote posture guidance between an instructor and a student. In this system, Kinect performs the 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 the first person perspective. In this regard, the student can view the movements of the instructor and can appropriate the posture when required. On the other hand, the instructor can guide the student to perform the movements properly when the student fails to do so. The authors evaluated the system in a laboratory setting across different conditions such as pre-recorded video and video conferencing. Their study showed that OneBody offered a better understanding of the posture to the students during the synchronous video conferencing. The authors described that the superimposed view of the instructor and student bodies supported more effective bodily communication than what is possible in a video conferencing through verbal communication. This finding mainly highlights the difficulty of communicating movements verbally in video consultations and the potential of using technologies to enhance the communication between remote ends. Although the system was not tested in the clinical setting, it has the potential to support physiotherapy related video consultations.

Other commercially available devices like Nintendo Wii-Fit Balance boards[3] are also utilised to support rehabilitation at home particularly for lower limbs. Wii-Fit board is a pressure sensitive board that captures the information of weight bearing balance. When the person stands on it and performs movements, the board checks the person's balance of the weight and visualises it on the TV screen. The balance is presented in the form of the percentage of the body weight the person is bearing on both legs, e.g., 45% on the left leg and 55% on the right leg. The board was developed as a gaming console, however, it was repurposed to support rehabilitation at home because of the ease of use. Consequently, some studies investigated the use of Wii-Fit board for different population groups, e.g., for improving the balance of older adults at home (Agmon et al., 2011), and to improve the functional abilities of people with Parkinson's disease (Esculier et al., 2012). These studies 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 provides a limited surface area for performing exercises, other researchers have also looked into pressure sensitive surfaces (Bongers et al., 2014) and pressure mats such as MatScan[4] to better support dynamic exercises like jumping and walking. These systems present the visualisation of the patient's weight bearing patterns on a computer screen using heat maps presented in the foot sketches. Bongers 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.

Although environmental tracking has benefits of being non-intrusive, it has issues related to capturing dynamic movements and to accurately capture certain body movements. For example, the Wii board is suitable for performing static movements

[3] Nintendo Wii-Fit Board http://wiifit.com/
[4] MatScan https://www.tekscan.com/products-solutions/systems/matscan

while standing, and cannot support the dynamic movements like walking. On the other hand, 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 the lower limbs (Huang, 2011; O'Hara et al., 2016; Tao et al., 2013). Hence, researchers have explored another dimension to sense movements by attaching sensors on the body. Next, I will discuss these advancements under on-body tracking systems.

On-body Tracking

On-body tracking systems, also called wearable computers, are the systems that track the movements through sensing units attached to the body. These systems can be attached to the body such as webcams, are portable to carry such as smartphones; can be worn under, on or may become clothes themselves such as smart clothing; and finally can go inside the body such as implantables (Mann, 1996). With the emergence of low-cost, small-sized and a wide variety of sensors, there have been significant explorations on developing on-body rehabilitation systems that can generate objective information about the patient's movements. Being attached to the body, these systems produce accurate data about the patient's movements. Table 2-6 presents a summary of the existing technologies using on-body tracking to support physiotherapy.

Several wearable systems are developed to support rehabilitation of different body parts. One common form for these systems include bands that the patients can fasten to monitor movements of their affected body parts. For instance, ArmSleeve (Ploderer et al., 2016) is a system designed to provide information to the occupational therapists about how the patients undergoing stroke rehabilitation use their upper limbs outside the hospital. The system is designed to support the clinicians' needs during face-to-face consultations. The system captures information related to range of movements of three joints, number of movements, time spent exercising, common postures of the arm and quality of movements measured on a scale of 1 to 10. It consists of a sensing unit that captures the patient's movements and a dashboard to present the captured data to the therapists. The sensing unit consists of three bands that the patient wear in three joints: wrist, elbow, and arm and shoulder joint. Each band is a standalone sensing unit consisting of an IMU sensor and other electronic components such as a storage unit and power supply to capture the arm movements. The dashboard design was evaluated with the occupational therapists at the hospital. 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 through the presented data (i.e., intention and purpose of the movement). 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).

System name	Body Part	Captured bodily information	Sensors used	Purpose
ArmSleeve (Ploderer et al., 2016)	Arm	Range of movement, number of movements, time spent exercising, common postures of the arm and quality of movements	Three IMU sensors on each arm	To support occupational therapists during face-to-face consultations
RVS (Ayoade and Baillie, 2014)	Knee	Range of motion	Two IMU sensors	To support knee rehabilitation at home
PT Viz (Ananthanarayan et al., 2013)	Knee	Bend angle	Bend sensor	Used as a probe to understand the needs of patients undergoing knee rehabilitation
Go-with-the-flow (Singh et al., 2016)	Lower back	Trunk movements and breathing patterns	Smartphones and two respiration sensors	To support patients having chronic back pain at home
BASE (Doyle et al., 2010)	Lower limb	Strength and balance of lower limb	Two SHIMMER kinematic sensors	To improve lower limb strength and balance of elderly people
Sensoria™ socks and shoes	Full body	Speed, pace, cadence and foot landing	Pressure sensors embedded in the socks and shoes	To improve postural stability while walking and running

Table 2-6: Summary of the existing systems using on-body tracking to support home rehabilitation.

Along the similar lines, band-shaped wearables are also developed to accurately capture the knee movements (Ananthanarayan et al., 2013; Ayoade and Baillie, 2014; Lam et al., 2016). For instance, Rehabilitation Visualisation System (RVS) provides real-time feedback to patients about the range of motion of their knees (Ayoade and Baillie, 2014). The angle is captured by two IMU sensors. The captured data is presented on a screen, where the angle is shown using a graphical fan with a changing color gradient. The system was evaluated with patients who have undergone knee replacement at their home. Their study highlighted 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 the physiotherapist use the system are not provided. For instance, 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 how the information is presented to the physiotherapists and the physiotherapists will use the system over-a-distance are not provided.

PT Viz (Ananthanarayan et al., 2013) is another system that detects the bend angle of the knee and provides visual feedback directly on the wearable. The system consists of two enclosures one for thigh and another for the calf. The knee angle is detected using a bend sensor, and the visual feedback is provided on a set of five bars attached to the thigh enclosure. These lines light up according to the degree of the 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 the patients undergoing knee rehabilitation in a usability study conducted in the lab. The study highlighted that the abstract visualisation was appreciated by the 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.

Singh and colleagues (Singh et al., 2016) developed a system to improve the quality of life of the patients having chronic lower back pain. The authors followed the user-centred design approach and interviewed both the patients and physiotherapists to develop their system. Their system, Go-with-the-flow consists of a smartphone and two respiration sensors, each attached to a band that the patient can wear to monitor the movements. The band with the smartphone is attached on the trunk of the patient and the bands with the respiration sensors are fastened on their chest. While the sensors of the smartphone capture information of the patient's trunk movements, the respiration sensors sense the breathing patterns, as the patient is doing the movements. Based on the movements, the system generates audio feedback using different types of sounds, such as the sound of moving water, wind-chimes and waves. They evaluated the system both in the laboratory setting as well as in the home setting. Their findings suggest that the audio feedback increased the patient's performance, motivation, and awareness of their movements while keeping them relaxed during exercising.

BASE (Doyle et al., 2010) is another system that is designed to improve the lower limb strength and balance of elderly people. The system supports elderly people at home by delivering them a personalised exercise program as prescribed by their physiotherapist. 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 patients in real-time. The sensing unit is a band consisting of two SHIMMER kinematic sensors that the patients wear near the ankles. The accuracy of the exercises is measured by tracking the movements through a webcam. However, the paper does not provide details of how the balance and strength data are visualised on the screen, and how does the physiotherapist use the Physio Console to set the exercise routine.

Additionally, sensing socks and shoes are also developed to help people in improving their postural stability in everyday routine. In this regard, Sensoria Fitness[5] socks 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 patterns of the person, e.g., speed, pace, cadence and foot landing along with the 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.

In summary, the review of the technologies supporting environmental and on-body tracking suggests three things: Firstly, the movement tracking systems have significant potential to help patients in managing their condition. The feedback offered by the system helps the patients to reflect on their progress and to appropriate their movements in order to achieve their rehabilitation goals. Secondly, this review highlights the potential and limitations of different technologies in capturing different types of movements. I utilised this knowledge later in the development of a wearable technology, described in Chapter 5. And finally, the review highlights the lack of attempts made to understand and support the needs of the physiotherapists in assessing and treating the patient’s body movements, with no system designed specifically for video consultations. This thesis will explore the design of the video consultation systems to support the needs of the physiotherapists during video consultations.

With this, I conclude the review of the relevant literature around three topics: video consultations, bodily communication, and physiotherapy, which was conducted to address the problem of bodily communication in video consultations of physiotherapy

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[5] Sensoria Socks: http://www.sensoriafitness.com/

investigated in this thesis. Based on this review, I formulated three research gaps that I explain in the next section.

2.5. Research Gaps

The review of existing literature in the area of video consultations, bodily communication and physiotherapy highlight the following three research gaps that guided this research.

Gap 1:	There is a limited understanding of how bodily communication happens during video consultations of physiotherapy, and how physiotherapists and patients perform different bodily interactions over-a-distance.

While there are partial accounts of how the clinicians and patients exchange bodily information during video consultations, a comprehensive understanding of how bodily communication happens throughout a video consultation of physiotherapy is missing. For instance, some studies suggested the lack of bodily cues like eye gaze, body orientation and facial expressions over the video that are essential for supporting rich conversation between the patients and clinicians (Bulik, 2008; Cukor et al., 1998). The absence of the essential bodily cues influenced the communication pattern such as turn taking between the clinicians and patients. On the other hand, some works appreciated video consultations in supporting certain bodily information that was not available in face-to-face consultations. For instance, clinicians were able to detect tongue tremors in the patient's speaking (Tachakra and Rajani, 2002), and parents felt closer to the speech therapist because of the specific spatial arrangement over video (Aggarwal et al., 2015). However, these works only provide anecdotal evidence of how video technology mediates different bodily information between the patients and clinicians, with little insight as to how these limitations or benefits had an impact on the overall clinical outcome in terms of assessment and treatment of the patients.

While adjustments through verbal communication can be made by the remote callers, they may not sufficiently support the bodily interactions in physiotherapy related consultations where bodily communication is fundamental. In this regard, a detailed understanding of what aspects of bodily information are important across different phases; what bodily information is missing in what phase of the video consultation; and how does the presence or absence of certain bodily information influence the ability of the patients and physiotherapists in fulfilling the consultation tasks, is needed - which this research aims to offer. Such an understanding will ensure that the introduction of the video technology does not hinder the specific needs of the physiotherapists and patients when the consultations happen over-a-distance.

Gap 2:	There is a limited understanding of how physiotherapists conduct assessment and treatment of patients during video consultations, and how the video technology supports physiotherapists in conducting their clinical tasks.

The second gap is a limited understanding on whether and how the physiotherapists understand the bodily information related to the patient's condition during video consultations, and how does the video technology influence their overall assessment and treatment process. In the clinical domain, the line of investigation has majorly been patient-centric, i.e., to understand the needs and experience of the patients with video consultations (Miller, 2011). On the other hand, the focus of HCI research has been on understanding the needs of the clinicians, e.g., how do the remote clinicians perform collaborative tasks over video, and how can different forms of technologies support these collaborations. And in doing so, these studies investigated video consultations between remote clinicians (Mentis et al., 2016a), or between a patient and clinician when the patient is accompanied by an assistant such as a nurse or GP (Larsen and Bardram, 2008; Stevenson et al., 2010). The assistant at the patient end acted as a proxy to conduct the necessary clinical tasks, as guided by the clinician at the other end. However, having a proxy clinician defeats the overall purpose of organising video consultations, where the aim is to support patients when they do not have an easy access to the health care services.

To this end, what is missing is an understanding of how video technology supports clinicians in assessing and treating patients over video, in situations when the patient is not accompanied by an assistant. Supporting the clinicians during video consultation is crucial because the efficacy of a consultation depends upon how well the clinicians can perform different tasks related to assessment and treatment (as seen in Section 2.2.5). For instance, the lack of understanding of the patient's condition reduces the clinician's confidence, which in turn, influences the overall treatment outcome and patient's adherence to the treatment (Demiris et al., 2010; Dorsey and Topol, 2016; Stewart, 1995). Consequently, this thesis investigates video consultations from the clinician's perspective, first to understand the challenges they face in conducting their assessment and treatment over video, and then to better support them in conducting their tasks.

Gap 3:	There has been a limited development of new systems that can support bodily communication between the patients and clinicians during video consultations of physiotherapy.

And the final research gap is related to the little exploration in the design of the video consultation systems, as video consultations are majorly reliant on video conferencing tools having the audio-visual medium. While prior works indicate that video technology may not sufficiently support the interactions beyond conversations, little attempts have been made to design new video consultation systems that can support bodily communication. The applicability of the audio-visual medium is questionable specifically for physiotherapy related consultations, as the assessment heavily relies on the fine-grained details of the body movements. Understanding body movements may be challenging in video consultations because the physiotherapist only has access to the two-dimensional view of the patient. The limited exploration in the design of video consultation systems contradicts with the opportunities that the state-of-the-art interactive technologies present. For instance, interactive technologies have significantly advanced from desktop computers to miniaturised forms of ubiquitous computers that are embedded in our surroundings, and yet the video consultation systems are still limited to the typical audio-visual video conferencing tools. This thesis, therefore, investigates the use of new communication technologies to support bodily interactions between the patients and clinicians during video consultation of physiotherapy.

Motivated by these research gaps, this thesis investigates the role of interactive technologies in supporting the tasks of physiotherapists in video consultations and further explores the opportunity of designing novel systems to enhance the clinical efficacy of the physiotherapists. The main research question that I am exploring in the thesis is the following:

> How can interactive technologies support physiotherapists in understanding patient's bodily information during video consultations?

While the above question illustrates the generic aim of the thesis, I divide the question into three sub-questions, with each question forming a separate study. These three studies collectively answered the main research question.

> RQ1: How do physiotherapists interpret bodily information in the current practice of video consultations?

The first question addresses the first two gaps and aims to establish a detailed understanding of how bodily communication happens in video consultations of physiotherapy, and how physiotherapists assess and treat patients over-a-distance. To understand the interactions of the patients and physiotherapists, I will utilise the six phases of consultations established in Section 2.2.1. This structured understanding of the clinician-patient activities across different phases will highlight the challenges that physiotherapists face in fulfilling the goals of these phases during video consultations. The bodily interactions between clinicians and patients will be described by using the vocabulary of bodily information developed in Section 2.4.1 (refer to Table 2-4). However, the efficacy model described in Section 2.2.5, is not employed in this study because this was the first study of the thesis. Consequently, the aims were not defined right from the beginning. I will provide more details on how this study was formulated and how the aims were defined in the next chapter in Section 3.4.

This study highlighted the challenges encountered by the physiotherapists in understanding the patient's movements particularly related to lower limbs over video - which inspired the development of a prototype system, *SoPhy*. *SoPhy* is a wearable technology that captures key information related to lower limb movements of the patients and presents it to the remote physiotherapist in real-time on a web-interface. The design was followed by a laboratory evaluation which formulated the second study of this thesis.

RQ2:	How does *SoPhy* influence the efficacy of physiotherapists in assessing lower limb movements in (simulated) video consultations?

The second question addresses the third research gap and seeks to evaluate the influence of *SoPhy* on the ability of physiotherapists to assess lower limb movements during video consultations. I will take a stepwise approach to evaluate *SoPhy*, and therefore, this study is focused only on the assessment and not on the treatment. In order to investigate the influence of *SoPhy* on the clinical practice of physiotherapists, I will utilise the efficacy model described in Section 2.2.5. As the focus of the study is on assessment, I will evaluate *SoPhy* only against three aspects of the model, namely, *technical efficacy, diagnostic accuracy efficacy,* and *diagnostic thinking efficacy* because these three aspects are relevant in the Examination phase (as described in Table 2-2). This study confirmed the utility of *SoPhy* in enhancing the diagnostic ability of the physiotherapists during video consultations and highlighted its potential benefits in treatment. The study was then followed by the final study, where *SoPhy* was evaluated in the real-world setting to address the following research question:

RQ3:	How does *SoPhy* influence the efficacy of physiotherapists in assessing and treating lower limb movements in hospital video consultations?

The final research question evaluates the utility of *SoPhy* in supporting physiotherapists to assess and treat patients during video consultations. I will utilise the six phases of a consultation to understand the interactions of patients and physiotherapists with and around *SoPhy* at different times during a consultation. Also, in order to describe the clinician-patient activities, I will utilise the vocabulary of bodily information listed in Section 2.4.1 (refer to Table 2-4). And finally, I will utilise the mapping between the phases and efficacy model described in Table 2-2, to generate a detailed understanding of how *SoPhy* influences the ability of the physiotherapists in conducting their clinical tasks throughout a video consultation.

2.6. Summary

In this chapter, I presented a review of the existing works at the intersection of three topics: video consultations, bodily communication and physiotherapy. I also utilised the existing literature on face-to-face clinical consultations and video-mediated communication for non-clinical setting to take inspiration as well as to argue the need of this research. The literature review highlighted that there exists a limited understanding of how bodily communication happens during video consultations of physiotherapy; how video technology supports clinicians in assessing and treating patients over video; and finally, the limited exploration on designing video consultation systems around the specific needs and tasks of the given clinical domain.

Through this literature review, I also established the following three key concepts that I will utilise later to present the findings of the research studies: six phases of a clinical consultation (Section 2.2.1), efficacy model to evaluate new technologies for video consultations (Section 2.2.5) and a list of bodily information relevant for physiotherapy consultations (Section 2.4.1). In the next chapter, I will describe my methodological approach to conducting these three studies.

Chapter 3
Research Design

Overview: This chapter outlines the overall research design with justifications on different methodologies and methods employed in each of the three studies conducted to answer the research questions.

3.1. Introduction

The literature review presented in the previous chapter highlighted the limited understanding on how bodily communication happens in video consultations, and it ended with research questions that guided this research. In this chapter, I will outline the overall research design followed in the thesis to answer the research aims. I will start by restating the research gaps in the existing literature and the research questions explored in this thesis (Section 3.2). Section 3.3 describes the research methodology that guided this research with justifications for how the chosen methodology best answers the thesis questions. Section 3.4 provides an overview of each study with details on different methods and tools utilised to conduct each of the three studies. Section 3.5 describes the collaboration established with other organisation and the support received from other people to conduct this research.

3.2. Research Questions

The literature review in the last chapter highlighted three research gaps. Firstly, it was highlighted that the existing literature lacks a comprehensive understanding of how bodily communication happens in video consultations of physiotherapy. Challenges in physiotherapy related video consultations are inevitable because bodily communication is fundamental in physiotherapy, and that the existing literature on video-mediated communication both in clinical and non-clinical settings, illustrates the limitations of video technology in supporting bodily information. Secondly, the literature review highlighted the limited understanding of how video technology supports clinicians in conducting their clinical tasks during video consultations specifically in situations when a clinical assistant (like a nurse or a GP) is not present with the patient to assist with the required clinical tasks. And the final research gap is related to the little exploration in the design of video consultation systems in order to support the clinician-patient interactions specific to a clinical domain.

Motivated by these gaps, this thesis attempts to generate an in-depth understanding of the importance and communication of bodily information in video consultations of physiotherapy, and aims to support the tasks of physiotherapists through novel interactive technologies. The main research question explored in the thesis is:

> How can interactive technologies support physiotherapists in understanding patient's bodily information during video consultations?

This research question is further divided into three sub-questions, where each question formulates a separate study.

RQ1:	How do physiotherapists interpret bodily information in the current practice of video consultations?
RQ2:	How does *SoPhy* influence the efficacy of physiotherapists in assessing lower limb movements in (simulated) video consultations?
RQ3:	How does *SoPhy* influence the efficacy of physiotherapists in assessing and treating lower limb movements in hospital video consultations?

I carried out three studies to answer the corresponding sub-questions, where the outcome of each study motivated the design and conduct of the consequent study. Study 1 started with a broad aim of understanding the overall challenges of physiotherapists in interpreting bodily information during video consultations. The focus on supporting lower limb movements in video consultations emerged from the findings of Study 1 and continued for the next two studies. All the three studies collectively address the main research question. Because of the specific questions addressed in each study, I followed different methodologies to achieve the research goals. In the next section, I will discuss the overall research methodology that guided the design and conduct of these three studies.

3.3. Research Methodology

Given the nature of the research questions addressed in this thesis, I employed a mixed methods approach (Creswell and Clark, 2007) to conduct this research. Accordingly, I employed different methodologies, namely, field research, experimental research and field deployments in different studies. Table 3-1 presents an overview of the research aims, research site and methodologies that guided the conduct of each study.

The first step of this research was to gather a detailed understanding of how clinicians and patients interact across different phases of a physiotherapy video consultation; how bodily communication happens over video; and what challenges do clinicians face in assessing and treating patients remotely. This knowledge can only be constructed in natural settings and hence, I employed the Field Research methodology (Neuman, 2011) to begin this research. Using fieldwork methods like participants observations and interview, I constructed knowledge of the relevance of bodily communication in physiotherapy consultations.

Insights of Study 1 guided the development of a novel prototype, *SoPhy. SoPhy* is designed to capture and communicate key bodily information related to lower limb movements to offer physiotherapists a better understanding of the patient's recovery during video consultations. Development of this technology required knowledge of the Physiotherapy practice, e.g., detailed understanding of what parameters are critical for

Study	Study Aims	Research Site	Methodology
Study 1	To understand how physiotherapists interpret bodily information in video consultations	Children's hospital	Field research
Study 2	To understand how *SoPhy* influences the efficacy of physiotherapists in assessing bodily (ie lower limb) movements in (simulated) video consultations	Usability lab in the university campus	Experimental research
Study 3	To understand how *SoPhy* influences the efficacy of physiotherapists in assessing and treating lower limb movements in hospital video consultations	Children's hospital	Field deployments

Table 3-1: Different methodologies were used to conduct different studies.

physiotherapists to assess and treat lower limb movements, and how to meaningfully present this invisible bodily information to physiotherapists. Consequently, I collaborated with a physiotherapist from the collaborating hospital and constructed the knowledge by following human-centered design approach (Rogers et al., 2011). Working with the physiotherapist helped me to iteratively design a prototype that can support the activities of physiotherapists during video consultations.

The next step was to evaluate the designed prototype to understand how it helps physiotherapists in assessing patients with lower limb issues during video consultations. I decided to evaluate the prototype in the laboratory prior to evaluating it in the natural hospital setting. Laboratory evaluation was critical because field deployments are resource intensive (Siek et al., 2014) and the use of inefficient technology in sensitive settings like video consultations may adversely influence the relationship between patients and clinicians (Blandford et al., 2015). Also, since this study was an important step to field deployments in the hospital setting, it required rigorous evaluation of the prototype. Hence, I employed Experimental Research methodology (Gergle and Tan, 2014) as it offers ways to investigate the role of different variables influencing the potential use of a designed prototype. I mainly relied on qualitative data to understand the relationship between different variables but complemented it with quantitative data to add more precision to the generated data. In line with other authors (Babones, 2015; Bhattacherjee, 2012), the combination of both quantitative and qualitative data provided meaning and context to different variables tested in the study, where qualitative data painted the use-case scenario and quantitative data established the significance of the designed prototype in the clinical practise of video consultations. This study helped me to answer *what* aspects of the designed prototype were important for physiotherapists and *how*.

Finally, the last step was to understand how the designed prototype influences the assessment and treatment process of physiotherapists during video consultations in hospital setting. Again, I required a field research approach that allows evaluation of a prototype in natural setting. I employed Field Deployments methodology (Siek et al., 2014) and studied the use of the system with patients and physiotherapists in video consultations. The study involved construction of the knowledge by interpreting social interactions between patients and physiotherapists with and around the designed prototype. This approach was best suited here to get rich stories of *how* and *when* the designed prototype helped physiotherapists during video consultations.

Below I will discuss each methodology individually to describe how the chosen methodology guided the design of the corresponding study.

3.3.1. Field Research

I followed Field Research approach to conduct Study 1, where the aim was to understand the challenges that physiotherapists face in interpreting bodily information related to patient's condition during video consultations. Since this was my first study, formulating the challenges required a detailed understanding of the current practises of video consultations and the interactions between patients and physiotherapists. Hence, I was looking to answer questions like what type of technologies patients and physiotherapists use to organise remote consultations; what activities do they perform in video consultations and how is it different from the traditional face-to-face practises; how does the use of technology differ at different times of a consultation. These questions can only be answered by being present in real video consultations, hence I adopted Field Research methodology to conduct this study.

Field research is an umbrella term to conduct research in natural settings (Neuman, 2011). It involves answering questions related to the social phenomenon through long term interactions with people in the target social settings. These long term interactions help the researchers to acquire an "inside" perspective on both the tacit and explicit knowledge practised by the site members. Field research lies on the principle of naturalism and supports interpretive perspective to its core. The field researcher is present in the natural setting and directly interacts or observes the social interactions to understand how and why people do certain things. Being present in the same setting, the researcher experiences the phenomenon, connects with the field members, and constructs knowledge by interpreting the ongoing social actions. My field research approach is strongly influenced by ethnography, however to avoid any misinterpretation, I will not name it as ethnography. For instance, over the years, researchers have defined different variations of ethnography such as sensory ethnography (Pink, 2015) and rapid ethnography (Millen, 2000) to address the ongoing debate on whether and how HCI researchers can follow ethnographic study. Instead I will use the generic term 'field research' to describe my methodology.

While field research in social science requires prolonged involvement with the site members (Neuman, 2011), field research in HCI is generally short and does not always involve living with the members of the site (Randall et al., 2007). Yet, it still takes a sufficient time to understand a setting and to gain a coherent view of the socio-technical phenomenon under investigation (ibid.). The length of the field research depends upon the problem and specifics of the field site. Since this research involved investigation at the hospital setting, Study 1 continued for eight months. Several factors influenced the course of the study, some of them include: availability of the patients and physiotherapists and availability of video consultations to observe particularly because video consultation is still an emerging practise. I will provide more details on these factors in Chapter 4.

Neuman (Neuman, 2011) described that field research follows a less structured and flexible structure, where the field researcher deals with several unexpected events and challenges. The first challenge starts with getting access to the field site and getting pass through the gatekeepers. Neuman (ibid.) mentioned that the gatekeepers play a crucial role in shaping the direction and focus of the field research. Similarly, in Study 1, the focus of this thesis on physiotherapy was defined due to the substantial and consistent access to physiotherapy consultations in comparison to other clinical domains. Since the physiotherapists at the collaborating department were supportive and interested in this research, their support helped me to understand their clinical practise as well as their challenges with video consultations. (I will provide more details on how the aims were defined for this study in the next section.) However, gaining clinician's trust and establishing rapport with them was not straight forward. I started taking up different roles. As an example, the physiotherapists greatly appreciated any technical support to set up for the video consultations, e.g., setting up the webcam or checking the working of the audio system. The relationship grew over time and I became a part of the consultation room and by the end of this study, clinicians started introducing me as their colleague to the patients.

Another challenge is related to the conduct of the field study. Since field research investigates a less known phenomenon, the study aims are not defined from the beginning (Neuman, 2011). The research starts with a broad focus where the field researcher first acquires a general picture of the site. After developing a good understanding of the people and their interactions, the field researcher gradually focuses on specific problems or issues. To support such investigation, Neuman (ibid.) suggests applying multiple viewpoints simultaneously to analyse the events. Accordingly, the Study 1 also started with a broad aim of understanding the user experience of physiotherapists and patients with video consultations, and the focus on bodily communication and the associated challenges in video consultations emerged gradually. Over time, I applied different concepts and theories from the existing literature to continuously reflect on the data. I adopted the attitude of being naive that Neuman (ibid.) suggested to learn the clinical practise of physiotherapists. (More details on the framing of study aims are provided in the next section as well as in Chapter 4).

For all other challenges, I followed Neuman's (ibid.) strategies of being spontaneous, honest and adaptive to the site members. Since this study was the starting point of the thesis, I maintained good relationship with the physiotherapists and other gatekeepers, and worked with them for the consequent studies of this thesis. I will now describe the methodology used to conduct Study 2.

3.3.2. Experimental Research

I employed Experimental Research methodology to conduct Study 2, where the aim was to evaluate how *SoPhy* helps physiotherapists in assessing patients with lower limb issues during video consultations. Given the aims, a comparative study with standard video consultation practise was required to evaluate if the proposed technology improves the efficacy of video consultation, and hence experimental research was followed. Experimental research plays a crucial role in clinical settings because clinical consultations involve complex and safety-critical situations, making it challenging to test the prototypes directly in the field (Blandford et al., 2015; Blandford and Berndt, 2010). In this regard, experimental studies serve as a precursor to the field evaluation of a new prototype in clinical setting. The methodology offers an effective way to evaluate a new system or design possibilities in a lab setting with less time and resource investment than required for conducting field deployments (Gergle and Tan, 2014). It allows researchers to first ensure that the new system has a potential for patients and clinicians and that the new system does not disrupt their practise before deploying it in the real-world setting. Additionally, since I designed a wearable technology for patients, I also aimed at ensuring that the new technology does not introduce any discomfort to the patients – which is again feasible through experimental research instead of testing it directly with patients who are already in pain. Hence, I utilised experimental research to evaluate the design of *SoPhy* before deploying it in the field. (Chapter 6 provides details of the lab evaluation of *SoPhy*.)

Experimental research is widely used in HCI to test different parameters of new systems such as quality, utility and usability against existing systems or with respect to a theory. The aim of experimental research is to demonstrate relationship between two variables (or more) of interest, where the researcher manipulates one variable to show a direct causal influence on another variable (Cook and Campbell, 1979; Gergle and Tan, 2014). Experimental studies can be designed to study the effect of single independent variable on a single dependent variable, as well as to study the effect of multiple independent variables on multiple dependent variables. The later approach is called as factorial design approach that I followed in Study 2. In Study 2, I had two independent variables - consultation technology and pain levels, and multiple dependent variables (e.g., range of movement and confidence). This approach allows researchers to investigate more complex relationships between independent and dependent variables.

While following the factorial design approach, I employed within-subject design in Study, where each participant was assigned to all the test conditions. Within-subject design allows researchers to study same participant under different conditions and therefore, provides opportunities to investigate how participants react to different conditions both individually and in unison to stand out comparisons. However, within-subject design also trails the issue of learning effect where participants may learn something in the former condition(s) that influence their later performance for different conditions. To minimise the learning effect, I used counterbalancing technique and randomized the order of study conditions across participants.

Obtaining External Validity

The biggest challenge with experimental research is the degree to which the study claims hold true for other contexts or settings, the condition is referred to as *external validity*. The virtue of controlling the external factors in a laboratory setting may create a situation that the observed behaviour of the participants does not illustrate a true picture of user behaviour in the real-world setting for which the system is designed. To boost the external validity of experimental research, Olson and colleagues (Olson et al., 1993) described three strategies that researchers should consider while designing an experiment. I utilised these strategies to design the conduct of Study 2. Below I will describe the three strategies with justification to how the strategies were utilised in Study 2.

- *Define representative tasks.* The first strategy suggests that the tasks for participants should be representative of user activities performed in ecologically valid settings. I followed this strategy in Study 2 to define the tasks for the actor (mock patient) and participants (mock physiotherapists). In the study, the actor performed different lower body exercises according to the given patient profiles, whereas the participants assessed the patient's movements during video consultations. The study tasks were carefully selected through the insights gained from Study 1 and were verified with the collaborating physiotherapist (details on the collaboration are provided in Section 3.3).

- *Recruit representative participants.* The second strategy recommends recruiting those participants who closely represent the target users of the developed prototype. Following this, I recruited postgraduate physiotherapy students in Study 2 to evaluate the utility of *SoPhy* in conducting the assessment during video consultations. These students gain skills to assess and treat patients with different health issues and are required to assist physiotherapists at hospitals for 19 to 37 weeks as part of their degree programme. After completing the degree, these students practice as full-fledged physiotherapists at hospitals. Hence, these students were the closest cohort of participants to evaluate *SoPhy*.

- *Select representative assessment criteria.* The final strategy suggests selecting the assessment criteria that is closer to what is followed in the target setting. As such, the assessment criteria should help the researcher in evaluating the specifics of the system and participants' activities and should be feasible for an experimental setup. I utilised this strategy to evaluate the tasks performed by participants in Study 2. This was the most challenging strategy to incorporate in the study because of the given study aims. The study was focused on evaluating whether and how *SoPhy* supports the tasks of physiotherapists by providing the key parameters of lower limb movements that were found limited in Study 1. In this regard, my aim was to understand how participants (physiotherapists) utilise the information provided by the system to assess patients, rather than evaluating their clinical expertise in assessing patients altogether (which is out of the scope of the thesis). In pursuit, through multiple discussions with my supervisors, I designed a Patient Assessment Form, where the participants were required to score their understanding of the different parameters (e.g., weight distribution and confidence) on a Likert scale.

Criteria to Evaluate Experimental Research

To maintain the validity and reliability of an experimental research, Abelson (Abelson, 1995) defined the M.A.G.I.C model that stands for Magnitude, Articulation, Generality, Interestingness, and Credibility. I embraced this model to evaluate the quality of the Study 2 findings. I describe the MAGIC criteria below with justification on how the criteria were met in Study 2.

1. *Magnitude* – Magnitude talks about the impact the findings of the experiment make to the real-world. Magnitude assessment goes beyond reporting the statistical significance of the results, i.e., the *p* value because *p* value in itself does not suggest whether the difference is meaningful or not. Magnitude can be determined from the practical implications of the experiment, such as the study design, methods employed and the overall study conduct, that might have an influence on the dependent variables. For instance, giving high compensation to participants may result in favourable results and thereby, generating less practical results. To achieve greater magnitude of the Study 2 findings, I took inspiration from other HCI works that have followed experimental research. For instance, the concept of actor to get consistency in performing patient's conditions was inspired from the study of OneBody system designed to support home-based physiotherapy training (Hoang et al., 2016). Additionally, simulating video consultations in the laboratory and using different patient personas were motivated from the work of Lee and colleagues (Lee et al., 2015), where the authors evaluated clinician's decision-making ability during video consultations through a simulated laboratory study. Furthermore, I utilised Aligned Rank Transform (ART) approach to analyse the data collected from the study, as it is already followed in HCI to analyse experimental studies having factorial design (Wobbrock et al., 2011).

2. *Articulation* - Articulation refers to the rich account provided to elaborate the study findings. Along with the statistical data, the researchers should describe the meaning of the presented data, e.g., how is the significant difference between two variables valuable with respect to the study aims. To support this, I have utilised a combination of qualitative and quantitative methods to report the findings of Study

2. For instance, while reporting the statistical data, I utilised qualitative data such as interview quotes from participants or accounts of participant observation, to illustrate its meaning.

3. *Generality* – Generality describes the extent of external validity of the experiment results, i.e., to what extent the findings can be applied to other situations and social arrangement with different people and at different times. To achieve generality of Study 2, I followed the three strategies, discussed in the previous section, for achieving external validity of findings. Also, Study 2 was followed by a field research, where I deployed *SoPhy* in naturally occurring video consultations at the hospital (in Study 3). Study 3 not only confirmed the findings of Study 2, but also revealed new insights on how *SoPhy* became a part of the overall video consultations. Hence, the conduct of Study 3 also confirmed the validity of Study 2 findings. (Chapter 6 & 7 respectively provide details of Study 2 and Study 3.)

4. *Interestingness* – Interestingness talks about the importance of the study findings and can be achieved through three aspects: theoretical, practical and novelty. Firstly, findings can inform new concepts, models or laws, and thereby, making theoretical contributions. Secondly, findings can make practical contributions by devising practical guidelines or design checklists that can solve the everyday problems. And finally, the novelty aspect can be fulfilled if the findings describe the use of new systems or tools. With regards to Study 2 of this thesis, the study findings accomplished interestingness around all the three parameters. Firstly, the study involved evaluation of a novel system *SoPhy* that is designed to enhance clinician's ability to assess and treat patients during video consultations (satisfying the novelty aspect). Additionally, the study utilised different aspects of the efficacy model to evaluate the utility of *SoPhy* (fulfilling the theoretical aspect). And finally, the study highlighted certain design considerations to inspire the design of future video consultation systems as well as to guide how to integrate novel systems in the clinical practise (satisfying the practical aspect).

5. *Credibility* – Credibility of an experimental research is achieved by convincing the readers and reviewers that the research followed the established practice and that the claims provide new insights into the literature. This is achieved by providing rich narration on what was done and how, listing the study limitations, performing appropriate analyses on the data, and correctly reporting the findings. To establish the credibility of the experiment conducted in Study 2, I have given a detailed description of the study methodology covering the study choices, tools for data collection and analysis and detailed description of the statistical data in the findings. Moreover, the study results are published as a full paper in the proceedings of ACM CHI 2017, which is a tier-1 conference in the field of HCI and follows a rigorous peer-review process to ascertain the credibility of research.

3.3.3. Field Deployments

I employed field deployments methodology to conduct Study 3, where the aim was to understand how *SoPhy* helps physiotherapists in conducting assessment and treatment of patients with lower limb issues during video consultations, and how it influences the overall efficacy of video consultations. Since the focus was on understanding the interactions of physiotherapists and patients with *SoPhy*, I conducted field deployments of *SoPhy* in naturally occurring video consultations at the hospital.

Field deployment is a form of field research that enables researchers to study the user interactions with a novel system in the target context (Rogers and Marshall, 2017; Siek et al., 2014). In field deployments, the system to be tested is installed in the everyday life of the target users for a certain period of time (varying from a couple of days to months). This allows researchers to study how users use, adopt, adapt, or abandon the technology in the real-world context, and how the system would operate in their everyday life, if used in the future. Field deployments provide a rich account of the acceptability, suitability and usability of a novel technology in-situ. Unlike experimental studies, field deployments allow the technology to interact with other aspects of the environment such as social and organisational structure, everyday distractions, and concurrent activities. Therefore, it unfolds the interplay between novel technologies, target user group, and social factors in everyday context. As such, the empirical evaluation of a novel technology in-situ allows researchers to peep into the probable future and thereby, informing opportunities for future designs.

Within HCI, the growing interests towards ubiquitous computing and Research through Design interventions have advanced the use of field deployments to evaluate the use of novel technologies in the field (Rogers and Marshall, 2017). Researchers employ a wide range of qualitative and quantitative methods to gain a rich understanding of the context under study (ibid.). In the clinical setting, previous studies have majorly utilised observations to understand how the clinical staff engages with the technology during their busy schedule and while giving care to their patients, in an unobtrusive way (Blandford and Berndt, 2010). Besides observations, other methods such as interviews, surveys, and audio-visual recordings are carefully chosen depending upon different factors such as the sensitivity of the context under study (e.g., ICU rooms), availability of the study participants (e.g., access to nurses in their busy schedule), duration of the task at hand, and privacy of the patient (e.g., patients in unconscious and barely covered state during surgery) (ibid.). Building upon the prior studies, I utilised observations and semi-structured interviews in Study 3 to understand user interactions with *SoPhy*.

I followed semi-controlled studies to deploy *SoPhy* in real video consultations at the hospital setting in Study 3. During the study, I investigated the use of *SoPhy* with the same physiotherapists who participated in Study 1. The relationship grew stronger particularly with one physiotherapist (pseudonym: Phil) as he showed a keen interest in the research from the beginning of Study 1. Both physiotherapists were kept informed about the progress of the project and the outcomes of different phases, e.g., the design phase of *SoPhy* and the outcome of laboratory evaluation. Being involved in this research increased their trust both in me and in *SoPhy*, which in turn, made the recruitment of patients feasible as they could motivate their clients to harness the benefits of *SoPhy* for their health conditions.

Deciding the Duration of Field Deployments

Field deployments are resource and time intensive for all stakeholders. Hence, an important but challenging factor for field deployments is to define the appropriate duration of deployments (Rogers and Marshall, 2017). While the behavioural scientists suggest following a period of six months for understanding the change in user behaviour (Prochaska and DiClemente, 1982), HCI researchers follow different practices and the duration varies from a couple of weeks to a few months (Siek et al., 2014). According to the behavioural scientists, participants may show greater engagement with the deployed technology at the beginning of the study, and their interests in the technology may fade off over time - which is important to find out the utility of the technology and is possible to uncover only through long-led studies. On the contrary, Miller (Miller, 2010) illustrates that new material things always acquire more attention from the user in the beginning. But as the material thing becomes a part of the surrounding, fading of interest is natural. Hence, fading of interest may not always suggest that the technology is no longer useful, as the device may have already had the desired impact (Rogers and Marshall, 2017). This suggests that short-led field deployments may also be able to provide stories around user engagement with technology provided that the study provide sufficient evidence of how the users adapt, adopt and accept the technology in their everyday (ibid.).

As such, the deployment period depends upon several factors such as the availability of resources to the researchers, user involvement in the study such that the tasks are not tiring for them, the context of deployment and most importantly, the research aims. For instance, Khot and colleagues (Khot et al., 2017) followed a two-week deployment of EdiPulse system because the research team had access to only one chocolate printer (approx. cost $5000) and participation required 1-hour engagement with the system every day. Although researchers decide the duration of field deployments around these different factors, deciding the duration beforehand may not be feasible in clinical research (Blandford and Berndt, 2010). Clinical setting involves multiple temporalities, which require researchers to decide the duration on the fly. For instance, duration may differ according to the availability of the patients satisfying the recruitment criteria, possibility of running multiple study sessions with the same patient, and finally finding clinicians who are not only keen but also available to participate in the given project.

Blandford and colleagues (ibid.) suggested intertwining the tasks of data collection and analysis to decide the ending of field deployments.

In Study 3, I concluded the field deployments of *SoPhy* at the collaborating hospital after a period of five months. The study was terminated as there were no more potential patients with lower limb issues and the collaborating physiotherapists were on annual leave for a month - suggesting that there would no more study sessions for at least one month. Waiting for another month was not feasible for my thesis submission timeline. Additionally, I continued the data analysis along with the data collection to continuously reflect upon what data I had already collected and what additional data was required to answer the research questions. Consequently, ending the study with four patients and one physiotherapist was considered legitimate as the collected data was sufficiently answering the study aims. To make this process transparent, I will provide more details of the data collection and analysis phase in Chapter 7.

Ending the Field Deployments

The ending of field deployments raises an ethical concern of removing the system from the field, specifically in the clinical setting if the system has proven to be beneficial for the patients and clinicians (Siek et al., 2014). One approach is to leave the system with the participants to allow them to continue using the system even after the conclusion of the study. However, in majority of the situations, the research prototypes are not robust enough to work as a standalone system, and maintaining continuous support by the research team is not feasible. Hence, the research team should keep their involvement clear from the beginning of the study so that the participants are well aware of what to expect from the study. While conducting Study 3, it was not feasible to leave *SoPhy* at the collaborating hospital for the future use, as the system was not robust enough for unsupervised usage. To avoid any expectations that cannot be met during field deployments, I clarified the study aims to participants right at the beginning of the study. For instance, before starting the study with a patient, I described that *SoPhy* is a research prototype and is available only for the study sessions. Such a clarification helped me to manage requests from patients and carers who were willing to carry *SoPhy* with them to practice exercises at home.

Criteria to Evaluate Field Research

Since field research focuses on interpreting a phenomenon through subjective viewpoints of the participants situated in a specific context, these interpretations are highly contextualised and therefore, less generalizable to other contexts. Because of the underlying epistemological assumptions that field research follows, the notions of reliability, validity, and generalizability are different in field research than experimental inquiry (Neuman, 2011). Morse and colleagues (Morse et al., 2002) underline that rigor in field research is as critical as in a positivist inquiry, the lack of which could make the research fictitious. Lincoln and Guba (Lincoln and Guba, 1985) provided a set of criteria to evaluate the rigor and trustworthiness of field research and described different techniques to guide researchers on how to achieve this criterion. Following their criterion, below I will evaluate the quality of Study 1 and Study 3 together, as both the studies follow field research methodology.

1. *Credibility.* Credibility refers to the confidence in the 'truth' of the generated findings. Field research is credible if the inferences presented are believable to the readers. To achieve so, I followed different techniques proposed by the authors (Lincoln and Guba, 1985). Firstly, following the *persistent observations* technique, I have provided a rich description of the study findings in both the study chapters to illustrate depth in my observations. Secondly, I adopted the *triangulation* of different methods to facilitate a deeper understanding of the research context, where data collected through one method was complemented by another method. For instance, I combined observations with interviews, as observations provided me with insights on 'what' and 'how' events unfolded in video consultations, whereas interviews complemented the data by providing insights on 'why' those events occurred in specific way. I also adopted the *peer debriefing* technique, where I discussed my interpretation of the context and of the data with my colleagues and academics in and outside of the university. Furthermore, I presented the study findings at different conferences, universities as well as at the collaborating hospital to get critical and timely feedback on my thinking. And finally, I utilised the *Member-checking* technique to ensure that the findings reflect the views of the target group i.e., the physiotherapists. Consequently, I conducted interviews with the participating physiotherapists and sought their feedback on the paper drafts.

2. *Transferability.* Transferability in the field research refers to the extent to which the findings can be applied to other settings, social arrangement, and people. Although the findings generated in this research are specific to the context of physiotherapy related video consultations and to the clinical practice followed at the collaborating hospital, I strove to make them applicable to other clinical contexts. In this regard, I have provided a rich account of the research processes and generated *thick descriptions* of the findings in both the study chapters. Also, following a sequential study design, the findings of study 1 are confirmed and extended in Study 3. Besides, the design dimensions generated from the insights of each study are also tested or adopted in the later studies. This validation of the findings and design dimensions not only perform the internal validity of this research but also illustrate ways on how to apply them in other settings. Finally, in each study chapter as well as in the Discussion chapter, I will also compare the study findings with previous studies in similar settings to highlight how this research extends or supports the existing literature.

3. *Dependability*. Dependability refers to the consistency and repeatability of the findings across researchers and methods. To achieve so, the inquirers should establish *audit trails* of their research to make the research auditable by external reviewers. Accordingly, I have provided a detailed description of the methods and tools used to collect and analyse data in the study chapters. I have also provided additional documents like observation and interview guides, and details of the initial rounds of data analysis in the corresponding appendices to make the research transparent to the readers. Additionally, by disseminating the findings of study 1 in ACM DIS 2016, this research has undergone *external audits*. For instance, DIS conference follows a double-blinded peer-reviewed process, where multiple researchers external to research review the work critically to evaluate the validity of the research. Their feedback played a crucial role in better articulating different arguments and in providing additional information to make the research process transparent to other researchers.

4. *Confirmability*. Confirmability refers to the degree to which the reported findings are neutral to any biases, motivation, and interest of the inquirer, and are shaped solely by the study participants. To demonstrate confirmability, I have mainly utilised the *reflexivity* technique suggested by the authors (Lincoln and Guba, 1985). In this regard, I will provide sufficient details on how the research questions were formulated for each study and why the study was designed in a particular way along with details on other possibilities that were ruled out. (Section 3.4 will provide more details on the possible options for conducting each study.) Additionally, in both the studies, I followed *triangulation* of data collection methods and different concepts to generate a rich understanding of the context. For instance, while in Study 1, I adopted bodily communication and six phases of clinical consultations to collect data, Study 3 was supplemented with another concept of efficacy model to get rich perspective on the given context. Finally, being regularly supervised by three supervisors also helped me in validating any potential biases that may have emerged during the course of this research.

3.4. Study Design

This section provides an overview of the design of the three studies conducted as part of this thesis. For each study, I will first describe the study requirements and then will briefly describe the methods used for data collection and analysis. Different methods were carefully employed to conduct these studies, which were inspired by the sensitivity of the research context. Table 3-2 presents an overview of the study design for each study conducted to answer the research questions of the thesis.

Study (Methodology, #Participants)	Study aims	Methods used for data collection and analysis	Chapter No.
Study 1 (Field research, 7)	To understand how physiotherapists interpret bodily information in video consultations	○ Observations ○ Semi-structured interviews ○ Informal conversations ○ Photographs of the technology ○ Thematic analysis (both inductive & deductive)	Chapter 4 Appendix A
Development Phase (Human-centered design approach) Described in Chapter 5 & Appendix B			
Study 2 (Experimental research, 10)	To understand how SoPhy influences the efficacy of physiotherapists in assessing lower limb movements in (simulated) video consultations	As in Study 1, and additionally: ○ Video recordings ○ Questionnaires ○ Descriptive statistical analysis ○ Nonparametric factorial analysis	Chapter 6 Appendix C
Study 3 (Field deployments, 5)	To understand how SoPhy influences the efficacy of physiotherapists in assessing and treating lower limb movements in hospital video consultations	As used in Study 1	Chapter 7 Appendix D

Table 3-2: An overview of the design of the studies conducted in this thesis.

To iterate, the main research question addressed in this thesis is:

How can interactive technologies support physiotherapists in understanding patient's bodily information during video consultations?

This research question is divided into three sub-questions, with each question forming a separate study. The outcome of these studies builds upon each other to collectively address the main research question. I will start by illustrating the design of Study 1.

3.4.1. Design of Study 1

Study 1 addressed the lack of a comprehensive understanding of how bodily communication happens in video consultations of physiotherapy and what challenges do physiotherapists face in interpreting the bodily information of patients over video. The research question answered in the first study is:

> RQ1: How do physiotherapists interpret bodily information in the current practice of video consultations?

Study Requirement

To address this research question, I was looking for a hospital site where video consultations are a part of the clinical practice. I collaborated with the Royal Children's Hospital in Melbourne as video consultation is an accepted practice, and clinicians from different departments regularly organise video consultations to meet their patients. I started the study with multiple departments at the hospital with a broad aim of understanding the user experience of video consultation systems, which included the understanding of the interactions between the participants with each other and with the underlying technology, technical issues, and the type of communication between patient and clinicians including both verbal and non-verbal. The broad aim is understandable because this was the first study of the thesis.

In fact, the conduct of this study defined the study aims and the thesis focus. To begin with, the focus on physiotherapy domain emerged over time. Initially, the fieldwork was open to multiple clinical domains like lung physiotherapy, surgery and Rheumatology to get a holistic understanding of the current practices of video consultations. However, I focused on physiotherapy because physiotherapists at the hospital were more open to having a researcher in the consultation room than clinicians in other domains. This is possibly because physiotherapy deals with less sensitive issues than consultations like surgery, where the patient is required to show body parts to demonstrate the recovery of wounds. Focussing on the physiotherapy consultations, in turn, refined the study aims and I focused on understanding the communication of bodily information in video consultations. The reason being that these sessions involved a significant role of non-verbal bodily information not only to support the verbal communication between patient and physiotherapist but also to assess and treat patients. Finally, the decision to focus only on the physiotherapists and not on the patients or carers was guided by the guidelines of the hospital ethics committee. Since patients involved in video consultations live in rural and remote areas, the committee felt that visiting the patients for observations would be risky for the researcher. Hence, physiotherapists became the main source of data collection for this study as well as for the consequent studies.

Justifications of the Methods

In my field research, I combined several methods to get an in-depth understanding of the challenges faced by the physiotherapists in interpreting bodily information during video consultations. I used traditional fieldwork methods including participant observations, informal conversations and semi-structured interviews for data collection (Neuman, 2011). Additionally, I followed the thematic analysis (Braun and Clarke, 2006) to analyse the data.

The choice of the data collection methods was inspired from the existing works on video consultations (Mentis et al., 2012; Stevenson, 2010) and clinical setting in general (Blandford et al., 2015; Furniss et al., 2014). For instance, Furniss and colleagues (Furniss et al., 2014) suggest that ethnographic methods like observations are suitable to understand the clinical practices, communication pattern, collaboration and decision making of the team. Hence, I adopted observations to understand the communication and interaction patterns of the patients and physiotherapists during video consultations. As such, observations helped me to get immersed in the setting and make my own experiences (Kawulich, 2005). Since I followed passive observations, it required no extra effort from the participants. I also utilised informal conversations, as it allowed quick reflections on the immediate events. Moreover, interviews helped me in uncovering personal opinions about the user satisfaction with the underlying system and the challenges with the system (Neuman, 2011). Interviews were used to complement the field observations, where I focused on understanding the reasons behind the observed activities and to validating my interpretation of these activities. Finally, I took photographs of the room to capture arrangement of the underlying technology.

An ideal study would have also included video recordings of the sessions, as video recordings allow researchers to review the session afterward to gain an in-depth understanding of the interactions. Video recordings and conversation analysis have been commonly used in the previous studies on video consultations (Agha et al., 2009; Nelson et al., 2010; Wakefield et al., 2008). These studies utilised video recordings to quantify the communication patterns between clinicians and patients during video consultations so as to bring a comparison with the face-to-face consultations, e.g., quantifying the number of utterances and short talk made by patients and clinicians to understand the communication differences in video and face-to-face consultations. Capturing the sessions through video recordings was essential in these studies, as these studies aimed at establishing statistical inferences on the feasibility and effects of conducting video consultations for patients.

However, I did not adopt video recordings because video recordings are described as an invasive method with concerns related to the patients' privacy and handling of the collected data (Furniss et al., 2014). Previous studies also highlight how participants adjusted their conversation in the presence of video recorders. For instance, Stevenson described that surgeons either followed certain sensitive conversations after the video consultation was over or asked the researchers to stop the video recording to make the patients comfortable (Stevenson, 2010). Since the participants in this study included patients below 18 years of age who were remotely present during video consultations, I aimed at keeping the setting naturalistic and comfortable for patients. Hence, I adopted non-invasive methods like observations and informal conversations to collect data during the session as these methods do not involve any privacy concerns. As a side effect, the choice of the methods also made the ethics approval easier at the hospital because the project involved low risk for participants. However, the lack of video recordings also implies that I may have missed making notes of some essential bodily information in my observations that patients and clinicians exchanged during video consultations.

During the field study, I captured my observations in notebooks, which included texts related to the conversation of the participants, and sketches about the room arrangement and activities of the participants such as exercises. Taking field notes in the notebook further relaxed the participants, as they could easily check my notes if they had any doubts. Interviews were audio-recorded for later analysis. On the other hand, data analysis went hand in hand with data collection. With the first observation, I also started analysing the data to reflect on the collected data as well as to refine the study goals. I personally transcribed all the collected data to familiarise myself with the data and the research context. I started coding the data while transcribing to highlight interesting events of the session. These codes were iteratively analysed to develop themes and sub-themes. I followed both inductive and deductive analysis to iteratively analyse the collected data in order to answer the research goals. While inductive analysis helped me to understand the practice of physiotherapy video consultations, the deductive analysis provided structure to the generated findings using concepts from the existing literature. For instance, I adopted the structure of six phases of clinical consultations (Byrne and Long, 1976) and the concept of bodily communication (Argyle, 2013) to illustrate the activities of patients and physiotherapists at different times of a video consultation.

I will provide more details of the data collection and analysis methods in Chapter 4 to make my approach transparent to other researchers. Additionally, I will use the appendix to provide examples of field notes, informal conversations and interview transcripts to make my research approach and outcomes auditable (Miles et al., 1984).

3.4.2. Development Phase

Building upon the insights gained from Study 1, this phase was dedicated to exploring the design space of video consultation systems so as to support the essential bodily information that was found challenging to interpret over video in Study 1. Since none of the existing systems at the time of this phase fulfilled my requirements, I decided to develop a new prototype system. The aim of this phase was to design a wearable technology that can capture the lower limb movements of the patients and communicate the information to physiotherapists in real-time during video consultations.

I followed the human-centred design approach (Rogers et al., 2011) to iteratively design the prototype such that the designed prototype fulfills the needs of the physiotherapists during video consultations. Consequently, I collaborated with a champion physiotherapist from the collaborating hospital to get an understanding of the clinical practice of physiotherapists as well as to get feedback on different iterations of the prototype. The physiotherapist also participated in Study 1, and hence he was not only aware of the research goals and but also the challenges of video consultations in supporting bodily communication. Additionally, he organises regular video consultations for his clients therefore, he could share his personal experience of using the video consultation systems. The physiotherapist also became a proxy to define the needs of the patients with the wearable system, as I had no access to patients during the development process.

The involvement of the physiotherapist started from the early phases of sketching out the potential design of the system to later iterations when the prototype was developed but further iterations were required to develop a system that fulfills the user needs. I held different meetings with the physiotherapist, where he tried out the wearable system as a mock patient and checked the visualisation templates to validate if the system would enhance his information space during video consultations. I do not refer to these discussions as interviews because these discussions were open-ended and followed a loose informal structure. Although the meetings were audio-recorded for later analysis, I did not follow the traditional way of transcribing these discussions because I was not looking for exact quotations from the physiotherapist. Instead, I turned to these audio recordings only when I needed to recall specific feedback from the physiotherapist. I majorly relied on the points I noted down during these meetings to reflect on his feedback. His feedback played a crucial role in defining the form of the wearable system as well as in deciding the technical components of the system for capturing the essential bodily information. However, discussions with him were limited because of his busy time schedule but I tried to best utilise these meeting times.

Along with the expertise of the physiotherapist, developing an interactive sensing technology for video consultations also required expert advice from the interaction designers and Electrical and Electronics Engineers. I, therefore, organised multiple discussions with experts from different disciplines to understand the possible technology (e.g., sensors) for developing the prototype as well as to validate if the developed prototype fulfills the interaction design principles. The outcome of this phase was a wearable technology, *SoPhy* that captures key aspects of patient's lower limb movements and communicates the information to physiotherapists during video consultations. *SoPhy* has two parts: a pair of socks that patients wear while performing lower limb exercises, and a web-interface for the physiotherapists to see the captured information in real-time. More details on the development are provided in Chapter 5 with additional documents presented in Appendix B.

3.4.3. Design of Study 2

Following the development phase, the next step was to evaluate whether and how *SoPhy* supports physiotherapists in assessing patients during video consultations, and what issues do they face in using the system. In this regard, Study 2 addressed the following research question:

RQ2:	How does *SoPhy* influence the efficacy of physiotherapists in assessing lower limb movements in (simulated) video consultations?

Study Requirement

This study required participation from multiple physiotherapists and patients to check the overall working of the system. However, recruiting physiotherapists practicing at the hospital was challenging because the study required participants to visit the university's usability lab and dedicate at least one hour to test different conditions. This, however, was challenging for physiotherapists because of their busy schedule. Additionally, the collaborating department at the hospital only has two physiotherapists - this number was not sufficient to make statistical inferences about the potential of *SoPhy* in video consultations. On the other hand, recruiting real patients was not appropriate for this study as it involved ethical concerns of evaluating a device that could cause discomfort to the patients. In fact, through this study, I aimed to investigate if the *SoPhy* socks were fine to be used by the patients in the real-world setting.

Consequently, I decided to conduct this study with post-graduate students from the Department of Physiotherapy of our university, as they were the best representative of the cohort. For instance, as part of their degree curriculum, these students complete a formal training in assessing and treating patients. I recruited students from the second and third (final) year as they already had some experience of practicing at the hospital. By the end of the second and final year, the students are respectively required to complete 19 weeks and 37 weeks of clinical practice at hospitals, where they assist physiotherapists in treating patients. Given their training and exposure to professional physiotherapists at the hospital, they were also well aware of the patients' behaviours for different issues. Consequently, these students played out the role of both the patients and physiotherapists in the study.

Justification of the Methods

Since the aim of this study was to investigate the efficacy of the new system in comparison with the standard video consultations, the study required an experimental methodology. I conducted this study in the usability lab at our university with the postgraduate physiotherapy students. The study was carefully designed considering that the physiotherapy students may not have any prior experience with video consultations, as video consultation is still an emerging practice. To this end, standard video consultations were kept as test condition so that the participants can compare their assessment with and without *SoPhy*. Additionally, to keep the study simple for a controlled laboratory evaluation, this study was focused only on the assessment and not on the treatment.

I intended to mimic the structure of video consultations as closely as possible in the lab in order to achieve greater external validity of the study findings. Consequently, I simulated video consultations across two rooms in the lab and used the same video conferencing software and arrangement of the screens as followed at the collaborating hospital. Besides, the study was designed in consultation with the collaborating physiotherapist who was involved in this research from the first study. His support was critical in deciding the tasks for participants such as the set of exercises to evaluate in the study, and in instrumenting tools (questionnaires) for data collection.

As the study was conducted in a controlled setting, I used multiple methods to evaluate the utility of *SoPhy* for physiotherapists. To generate a qualitative understanding about the use of *SoPhy*, I used the same methods that were used in Study 1, which includes participant observations, informal conversations, and semi-structured interviews. These methods were supplemented with video recordings of the sessions and two questionnaires to generate quantitative insights on the use of *SoPhy.* For instance, sessions were video recorded to make quantitative inferences on the user interactions with the *SoPhy*. Additionally, questionnaires were developed to understand what lower body information provided by *SoPhy* helped participants in formulating their assessment; and how comfortable are the *SoPhy* socks in wearing. As such, the data collected from the video recordings and questionnaires helped in establishing statistical inferences on the potential of the prototype in comparison to the standard practice of video consultations.

I employed Embedded mixed method design approach (Creswell et al., 2003) to present the data collected from both the qualitative and quantitative methods. In this regard, the findings were mainly qualitative with quantitative data playing a secondary role to support the qualitative insights. Like Study 1, I used the thematic analysis approach to analyse the collected data. For the analysis, the qualitative data was transcribed to develop codes and themes, and the quantitative data was analysed using different tests such as Descriptive analysis and Nonparametric factorial analysis to generate statistical inferences. As such, qualitative findings guided the analysis and use of the quantitative data. In the initial rounds of iteration, I conducted inductive analysis to allow new themes to emerge from the data that can describe the relationship between different variables. And in the last iteration, I analysed the data deductively to address three aspects of the efficacy model that were relevant to the study namely, *technical efficacy, diagnostic accuracy efficacy,* and *diagnostic thinking efficacy*. (The efficacy model is described in Section 2.2.5.) More details on the data collection and analysis are provided in Chapter 6 with additional documents presented in Appendix C.

3.4.4. Design of Study 3

Building on Study 2, the final study aimed at investigating the potential of the designed prototype in the real-world hospital setting to understand how *SoPhy* helps physiotherapists during video consultations. The study answered the following question:

RQ3:	How does *SoPhy* influence the efficacy of physiotherapists in assessing and treating lower limb movements in hospital video consultations?

Study Requirement

This study required a hospital site where video consultations are regularly organised and where physiotherapists will be interested in using *SoPhy* during video consultations. As I had already developed a good relationship with the physiotherapists from my previous field study (Study 1), I conducted this study at the same children's hospital. The physiotherapists were aware of the advancements of this research from Study 1 onwards with one physiotherapist closely involved in other activities since then such as prototype development and laboratory evaluation. Conducting the study with the same physiotherapists also influenced the design of the study, and I did not follow a comparative study of video consultations to understand their experience with and without *SoPhy.* Physiotherapists were able to compare their experience of having *SoPhy* with their previous sessions from Study 1. On the other hand, the study required participation from patients having lower limb issues because *SoPhy* is designed to capture information of the lower limb movements. These patients were recruited by the physiotherapists depending upon their suitability to try out the system.

Furthermore, *SoPhy* being a prototype system, required technical support during the study sessions. Hence, I required access to both the physiotherapists and patients during video consultations to support the use of *SoPhy*, which, however, was challenging as patients who essentially adopt video consultations live in rural and remote areas. Learning from my previous experience of Study 1, visiting the patients at their home was not considered an option, as the hospital ethics committee considered it risky for the researchers. Hence, local patients who visit the hospital for face-to-face consultations were recruited for the study, where their face-to-face consultations were converted to video consultations. These video consultations were organised across two rooms of the hospital, where the patient and physiotherapist met each other over video.

Finally, some study requirements also changed to be in alliance with the clinical practice of the hospital. In this regard, even though the study was focused only on video consultations, I conducted field deployments of *SoPhy* in both the face-to-face and video consultations. This was because the collaborating hospital follows a protocol, where all the new prototypes are first introduced to the patients in face-to-face consultations before using them in video consultations. Giving a short demonstration of *SoPhy* prior to conducting video consultation or at the beginning of the video consultation was not considered appropriate by the hospital staff because of the complex conditions of the chronic pain patients. Consequently, all the patient-physiotherapist pairs used *SoPhy* first in a face-to-face consultation and then in video consultation(s).

Justifications of the Methods

To understand how *SoPhy* helps physiotherapists in assessing and treating patients, I followed the field research approach and conducted field deployments of *SoPhy* in naturally occurring video consultations at the hospital. I used the same set of non-invasive methods as used in Study 1 - observations, informal conversations, and semi-structured interviews, to collect data of the user interactions with the designed prototype while keeping the setting naturalistic and comforting for the patients. For instance, I conducted participant observations during video consultations to understand when and how physiotherapists and patients used the designed system. Additionally, I also organised semi-structured interviews with both physiotherapists and patients to understand their overall experience with the designed system. Finally, I captured photographs of the room to capture arrangement of the developed technology, and of the patient's foot to record the use of *SoPhy* in different sessions.

Similar to Study 1, I utilised the thematic analysis approach to analyse the collected data, where the data analysis was intertwined with the data collection process. Since this was the last study, I mainly followed deductive analysis with the aim to confirm the findings of both Study 1 and Study 2. For instance, through this study, I wanted to confirm that *SoPhy* is beneficial in assessing patients even in the hospital setting as found in Study 2, and that it also resolves the challenges of video consultations discovered in Study 1. Additionally, the deductive analysis was also utilised to address different aspects of the efficacy model that were relevant to this study, which included *diagnostic accuracy efficacy, diagnostic thinking efficacy*, *therapeutic efficacy,* and *patient outcome efficacy*. In addition to the deductive analysis, I also followed the inductive analysis to allow new themes to emerge from the data (the process proved essential to refine the study aims). I will provide more details on the data collection and analysis procedures in Chapter 7 with additional documents in Appendix D.

3.5. Collaboration

This thesis lies at the intersection of HCI and clinical domain, where I aim to investigate the role of interactive technologies to support the assessment and treatment of patients undergoing physiotherapy during video consultations. Due to the nature of the research questions explored in each study, all studies were carried out in collaboration with other organisations, researchers and software developers. Although other people and organisations helped me in conducting the studies, all the data collection and analysis were conducted solely by the author of this thesis (referred to as the researcher). Details of who was involved at what phase of the different studies are discussed below. All studies were conducted under the supervision of my supervisors - Prof. Frank Vetere, Dr Bernd Ploderer, and Dr Thuong Hoang.

Chapter 4 describes the observational study of video consultations to understand the challenges faced by the physiotherapists in the current practices of video consultations. This study required access to a hospital site, where video consultations are already followed as a clinical practice by the physiotherapists. Therefore, I collaborated with the physiotherapists from the Department of Anaesthesia and Pain Management, Royal Children's Hospital (RCH) in Melbourne. Physiotherapists at the collaborating department regularly organise video consultations for their patients with long-term chronic conditions. Collaboration with this department continued for all the other studies. Data collection and analysis was conducted solely by the researcher.

Chapter 5 involves the development of a research prototype *SoPhy*, which consists of a wearable component (*SoPhy* socks) and a software module (*SoPhy* visualisation). Development required access to both the technical and clinical knowledge so that the developed prototype can provide meaningful information to the physiotherapists during video consultations. Therefore, this study was conducted in collaboration with multiple people. Firstly, I collaborated with a senior physiotherapist – Mark Bradford from the collaborating hospital to understand the clinical practice and to get feedback on the prototype iterations. Additionally, I worked with my third supervisor, Dr Thuong Hoang who has expertise in developing wearable systems. And finally, I worked with a Masters student, Weiyi Zhang, who developed the software module of the prototype. The researcher guided Weiyi by providing her the conceptual design of the software in the form of paper prototypes. Weiyi developed the *SoPhy* visualisation as part of her Master's project. All the data collection and prototype iterations were conducted by the researcher.

Chapter 6 presents the laboratory evaluation of *SoPhy*. Since the study required participants to be arranged in two rooms, Weiyi Zhang helped the researcher in conducting the study by being present in the actor's room. She managed the technical issues with *SoPhy* at the patient side during the study sessions. Additionally, the study involved different parameters such as patient personas and exercises, which required clinical knowledge. Therefore, I worked with Mark Bradford to get feedback on the study design and to develop questionnaires for data collection. Finally, the study involved the quantitative analysis of the collected data, which was conducted under the supervision of Thuong Hoang. All the data collection and analysis was conducted solely by the researcher.

Chapter 7 describes the field deployments of *SoPhy* with the revised design following the insights from the laboratory evaluation (Study 2). The *SoPhy* visualisation was revised by Weiyi Zhang and Kun Liu, who were paid for their time. The researcher redeveloped the *SoPhy* socks in collaboration with Thuong Hoang. The study was again conducted in collaboration with the physiotherapists from the Department of Anaesthesia and Pain Management at Royal Children's Hospital. Furthermore, as the evaluation of *SoPhy* was conducted at two rooms of the hospital, Thuong Hoang helped the researcher in conducting the study. Thuong was present in the patient room to offer technical support for using *SoPhy* in the sessions. All the data collection and analysis were conducted solely by the researcher.

3.6. Summary

This chapter provided an overview of the overall research design followed in the thesis to address the research aims. I will conduct three studies, each employing a different methodology and methods to appropriately answer the corresponding research question. The exploration began with a field research to understand the current practices of video consultations (Study 1), which motivated the development of a wearable system *SoPhy*. The design phase was followed by a laboratory study (Study 2) and then by field deployments of *SoPhy* in the hospital setting (Study 3), to understand the influence of *SoPhy* in supporting the tasks of physiotherapists.

The next chapter presents the first study of this thesis, which was conducted at the Royal Children's Hospital. This study aimed at generating a detailed understanding of the challenges faced by the physiotherapists in assessing and treating patients during video consultations.

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Chapter 4
Study 1: Observations of Video Consultations

Overview: This chapter describes the first study of the thesis with details on the study procedure, findings and implications of the findings in the broader context of video consultations.

Key Publications: The content of this chapter is based on the following publications (listed in Appendix E.1 and E.2):
Aggarwal, D., Ploderer, B., Vetere, F., Bradford, M., Hoang, T., 2016. Doctor, Can You See My Squats?: Understanding Bodily Communication in Video Consultations for Physiotherapy. In Proceedings of the 2016 ACM Conference on Designing Interactive Systems. ACM, pp. 1197–1208.

Aggarwal, D., 2016. Supporting Bodily Communication in Video-based Clinical Consultations. In Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems, CHI EA '16. ACM, New York, NY, USA, pp. 188–192.

Public Presentations: Findings of this study were presented at the following academic venues:
ACM DIS 2016, Brisbane, Australia
Doctoral Consortium, ACM CHI 2016, San Jose, USA
4th Annual CIS Doctoral Colloquium, University of Melbourne, 2016

4.1. Introduction

The previous chapter laid out the research design for this thesis. Through three studies, this thesis will explore how interactive technologies can support physiotherapists in their assessment of bodily information during video consultations.

This chapter describes the first study of the thesis, which investigates the current challenges of bodily communication during video-based clinical consultations. The structure of the chapter is as follows: Section 4.2 describes the study aims, and Section 4.3 outlines the research context for the study. Section 4.4 provides details on the participants, study setup, and methods of data collection and analysis. In Section 4.5, I present the study findings by listing out ten challenges related to communicating bodily information across six phases of video consultations. Section 4.6 provides a discussion of the findings highlighting the implications of the limited access to bodily information for clinical practise of physiotherapists. The section also describes three design opportunities to invite future explorations in the area of video consultations. Later, I provide a summary of the contributions related to this study in Section 4.7, and finally conclude the chapter in Section 4.8.

4.2. Study Aims

This study was conducted in response to the first research question on:

> RQ1: How do physiotherapists interpret bodily information in the current practice of video consultations?

I divided the main research question into the following related sub-questions that guided my data collection for the study:

Q1. What types of bodily information do current video consultation systems support?

Q2. What are the limitations of video consultation systems in supporting bodily information?

Q3. How do technical limitations influence physiotherapists' ability to assess and treat their patients during video consultations?

To achieve the research goals, I conducted a qualitative study of video consultations where I observed both video and face-to-face consultations of physiotherapy. The reason behind observing face-to-face consultations was to get background knowledge of how physiotherapy related consultation happens in a physical environment, and what types of activities and interactions take place between physiotherapists and patients. I utilized this understanding to compare the strengths and limitations of video technology in supporting the required clinician-patient interactions. Ethics to conduct this study was approved by the ethics committee of the hospital, HREC# 35112A. (Appendix A.1 presents the plain language description of the project.)

4.3. Research Site

The study was conducted in collaboration with the Department of Anaesthesia and Pain Management, Royal Children's Hospital (RCH) in Melbourne, Australia. RCH is the leading children's hospital in Victoria that supports clients from several small and big cities. The hospital is at the forefront of trying out new technologies and methods to benefit their clients, and is enthusiastic in supporting research for the same. At the time of this study, it was the only hospital in Melbourne (and beyond) with video consultations as a formal clinical practice. The hospital has a dedicated telehealth unit with essential facilities such as IT services and a telehealth coordinator. The unit organises regular training programs for clinicians to help them in accepting video consultations as part of their practice.

The hospital started to offer video consultations of physiotherapy two years before the study was conducted particularly to help clients having long-term symptoms such as chronic pain. Chronic pain is a long-term condition where patients continue seeing physiotherapists for months or years, which can severely disrupt education, work life and social connections with peers (Chalkiadis, 2001; Jackson, 2011). Also, it is the third most costly health condition in Australia, as one in five young Australians (including both adolescents and children) live with chronic pain[6]. This is particularly significant as some patients in the study had to travel as far as 4000 km to see their clinician at the hospital. This research was therefore partially inspired by the local needs and emerging practice at the hospital.

At the hospital, rehabilitation for chronic pain consists of different phases (Chalkiadis, 2001). The first phase is education, where the whole family gets education about how pain happens and how they contribute to their child's condition, and how they can help their child to recover. After education, the patient undergoes training around three factors – physical, functional and psychological, where each factor is managed by a different clinical expert. For example, physical factor is related to improving and increasing the patient's movements - which is managed by a physiotherapist. Functional aspect is related to making the patient regular in performing activities at home and school, and is managed by an occupational therapist. Finally, the psychological aspect deals with the fear and anxiety of patients with different situations, and is handled by a psychologist. Consequently, a multi-disciplinary team works together to enable the patient to perform everyday activities normally. For the sake of this study, I mainly focused on the clinical practise related to physical rehabilitation, as performed by physiotherapists.

[6] Pain Australia. http://www.painaustralia.org.au/about-pain/painful-facts (Retrieved on 6 Nov. 2017)

4.4. Methodology

The aim of this study was to understand how physiotherapists interpret essential bodily information related to patients' movements during video consultations of physiotherapy. I employed field research approach (Neuman, 2011) to address these aims. The methodology to conduct this study was informed by the sensitivity of the clinical setting and the hospital ethics guidelines. In line with the challenges discussed by Blandford and Berndt (Blandford and Berndt, 2010), I also faced several challenges in studying video consultations that limited the resources for data collection and also stretched the study to 8 months. Together, these challenges created a complex research environment, which needed to be approached with care and sensitivity.

The four methodological challenges included the following: Firstly, since video consultation is a relatively new practice, most clinicians do not choose to undertake a video consultation. For those that do, their patients do not always agree. Thus, finding a suitable clinician-patient pair who utilizes video consultation was difficult. Secondly, consultations are organised around the patient's needs. In this regard, consultation frequency for a patient can vary from weekly to several months. Thirdly, video consultations often involve clinicians from different hospitals at remote ends. Their participation in the study requires separate ethics approval from the respective hospital, which was not always feasible given the lengthy process of obtaining ethics approval in the hospital setting. This further limited my access to video consultations. And finally, consultations involving vulnerable patients or sensitive conversations or new patient (first consultation) are typically not open for observations, as it could be intimidating for patients to discuss their health condition in the presence of new people (researcher). Hence, I missed out on several consultations that could have yielded in-depth insights about the current practice of video consultations.

Below I will discuss the details of the study participants, set up of the consultations and methods used to collect and analyse data.

4.4.1. Participants

I recruited physiotherapists based on their practice of organizing video consultations, while physiotherapists recruited patients according to their health conditions. To this end, physiotherapists decided what type of consultation - face-to-face or video - would be suitable for the patient. Also, to reduce the variation in communication style and practices of every clinician, I observed video and face-to-face consultations with the same physiotherapists. Additionally, I aimed to conduct multiple observations with the same patients, in order to understand the suitability of video and face-to-face consultations at different times.

I observed ten naturally occurring physiotherapy consultations over a period of eight months at the Department of Anaesthesia and Pain Management, Royal Children's Hospital. These consultations were organized by two physiotherapists: Phil and Peter, for five patients: Anna, Jenny, Laura, Camilla, and Susan (names changed). All patients were between 10-17 years of age at the time of the study. (I hold an approved Working with Children Check in addition to the hospital ethics to conduct research with young children.) They had chronic pain in different body parts - Anna and Jenny had pain in multiple body parts, Laura had pain in her knee and ankle, Camilla had shoulder pain, and Susan had chronic pain in her forehead. Table 4-1 enumerates all sessions in the order of their occurrence over 8 months. All consultations were follow-up consultations. Besides the patient and clinician, the consultations involved other people at different times, such as GPs and carers (as mentioned in Table 4-1).

All face-to-face consultations happened at the hospital. I observed the video consultations from the clinician's side at the hospital, while patients joined in the video consultations from their home (sessions 1, 6, 8, 9 & 10), or from the local hospital with their GP (sessions 4 & 5). Due to technical issues involved in making video calls, sessions 4 and 5 were organised over the telephone. Because these sessions were scheduled in succession on the same day, the technical issues that occurred in session 4 also influenced session 5.

4.4.2. Study Setup

During the study, the hospital staff utilised GoToMeeting[7] and HealthDirect[8] software to make video calls. At the clinician end, video consultations were organised using a desktop computer, webcam, telephone and speaker (microphone enabled). Patients, on the other hand, used a laptop as it offered the flexibility of moving the camera to support different activities during the course of the consultation. The hospital department has a dedicated room to organize video consultations with two computer screens and a telephone arranged on a table (refer to Figure 4-1). Physiotherapists attached their webcam to the existing computer right before the consultation. Peter also used an external speaker with an embedded microphone in session 9, whereas Phil used the inbuilt voice system of the existing computer for his sessions. In all the sessions, physiotherapists initiated the video call after checking the availability of patients on the software or over the phone, e.g., HealthDirect software allows patients to indicate their availability through a waiting room option. All video consultations ran for 60 minutes.

Both the physiotherapists used only one screen for organizing the video consultations, except for the last session (session 10) where Phil used the second screen to open up

[7] GoToMeeting. https://www.gotomeeting.com/en-au (Retrieved on 6 Nov. 2017)
[8] Health Direct. https://www.healthdirect.gov.au/ (Retrieved on 6 Nov. 2017)

Session	Type of Consultation	Child (patient)	Others at the patient end	Physiotherapist	Others at clinician end
1	Video consultation	Anna	Mother	Phil	Pain consultant
2	Face-to-face consultation	Anna	Mother, Father	Phil	Occupational therapist, Psychologist
3	Face-to-face consultation	Anna	Mother	Phil	Psychologist
4	Video consultation + Telephone**	Anna	Mother, GP	Phil	--
5	Video consultation + Telephone**	Laura	Mother, GP	Phil	--
6	Video consultation	Anna	Mother	Phil	Occupational therapist
7	Face-to-face consultation	Laura	Mother	Phil	Pain consultant, two trainees
8	Video consultation	Camilla	--	Phil	Telehealth manager
9	Video consultation	Jenny	Mother	Peter	--
10	Video consultation	Susan	Mother, Father	Phil	--

Table 4-1: Details of the observed consultations in the order of their occurrence: I conducted observations from the physiotherapists' end. Names of the participants are changed to protect their identity. (**Telephone was used when video connection failed.)

the patient's medical records. Physiotherapists were reluctant to use the second screen, as they felt that looking at another screen would take their attention away from the patient and make the patient feel like they were being ignored. Physiotherapists also used the telephone to contact patients when there were issues in the video call, e.g., telephone offered the audio connection when there were issues with the audio of the video call. Also, the telephone became the only medium for conversation when video

Figure 4-1: Setup of a video consultation: The hospital had a dedicated room for organising video consultations with two screens and a telephone already placed.

Connections failed, as was the case in sessions 4 & 5. Again, all telephone calls were initiated and disconnected by the physiotherapists. In all the sessions, physiotherapists brought different documents related to the patient's medical history such as pain diagrams or notes from the last consultation. (Refer Appendix A.2 for an example of pain diagrams used at the hospital.) During the consultation, physiotherapists took manual notes and sketched body diagrams on the hospital prescribed assessment form. They transcribed these notes digitally after the consultation.

In face-to-face consultations, physiotherapists used a computer screen to refer to the patient's medical history and to take notes during the session. In some sessions, the patient's carers also took notes on paper for the suggested exercises and the daily schedule that the physiotherapists (and other clinicians) recommended the patient to follow. They also brought the chart of the daily log of the activities that their child was developing on the recommendation of their physiotherapists. (An example of a patient's daily log is presented in Appendix A.3.) Additionally, patients had consecutive consultations with different clinicians on the same day. Face-to-face consultations followed the same time duration as that of video consultations, i.e., around 60 minutes.

4.4.3. Data Collection

I used a set of methods to gain rich insights on the activities between patients and physiotherapist during video consultations and the challenges faced by physiotherapists in video consultations. These methods included participant observations, semi-structured interviews, and informal conversations, and were inspired from earlier HCI studies in the clinical setting (Blandford et al., 2015; Chen et al., 2011). I also captured photographs of the setup (excluding participants) to understand the arrangement of the underlying technology. As such, I aimed to keep the setting naturalistic and comforting as these consultations were organized for young patients (under 18 years), and hence I did not opt for video-recording the sessions nor did I photograph the participants. The outcome of this phase was a collection of field notes and interview transcripts that guided the next phase of data analysis.

The data collection started with a broad aim of understanding the user experience of video consultation systems because this was the first study of the thesis. The study aims and focus were refined over time and finally, I investigated the challenges faced by physiotherapists in interpreting bodily information during video consultations. To refine the study goals, I conducted data analysis simultaneously with the data collection. I will describe the data collection and analysis phase separately for clarity, however, in reality, they were intertwined, with one shaping the other. Before describing the data collection methods, I will first illustrate the pre-study activities that I commenced to prepare myself for the study.

Preparing Myself for the Data Collection

Conducting this study required some preparation at my end because this study was my first exposure to observations and research in a clinical setting. Also, observations were the only source of data collection leaving me no other way to retrace the consultations. Hence, I prepared myself for conducting observations so that I do not miss any interesting events from the sessions. In order to understand how to observe and how to take notes in real-time, I tried observations in public places like university gardens. I also realised that taking notes would not be possible for me every time in a dynamic setting like a consultation room. Hence, I also practised observations without taking any notes and observed the activities of people in supermarkets. Later I wrote these notes in a diary. Similarly, I rehearsed interviewing with my colleagues at the university. Based on these rehearsals, I revised the framing of the interview questions to make them neutral from any bias or assumptions.

These rehearsals made me realize that observations require specific goals or lens, otherwise, it is easy to get lost in the dynamicity of the real-world setting. Consequently, I paid specific attention to developing a focused observation guide, and a good theoretical background to be aware of what to observe. However, since this was the first study, the aims were not refined from the beginning. I, therefore, read different theoretical concepts and the literature on video consultations to sensitise my observations. These concepts included user experience to understand the interactions of people with technology (McCarthy and Wright, 2007); proxemics to understand the perception of people about physical space (Hall, 1966); f-formations to understand the physical spacing and orientation of people during conversation encounters (Kendon, 2010); and finally, micro-mobility of physical artifacts that people utilize to mediate the information among themselves (Luff and Heath, 1998). All these concepts provided me with different lenses to understand the activities of the consultation room.

One of my concerns for the data collection was the ability to take notes quickly. To achieve this, I tried taking notes on iPads with predefined templates developed for note taking. However, taking notes digitally slowed down the process and I found myself writing in freestyle rather than using a template. I then decided to take notes using paper-pen, as I was more fluent in writing with pen and paper than taking digital notes. The benefits of taking manual notes are also iterated in the literature (Marcu et al., 2013; Ploderer, 2011). Additionally, I also tried to develop a set of shorthand notations and reviewed some of the already developed notations (Hall, 1963). However, referring or memorising the defined set of notations in real-time delayed my note making process, when I tried to rehearse with these notations. Hence, I went with a spontaneous note-taking process. Finally, in order to remind myself about the observation goals and to have focused data collection, I listed the observation goals on post-it notes that I attach on the starting page of the notes diary for reference during the session.

Participant Observations

The main source of data collection for this study was participant observations (Emerson et al., 2011). I conducted observations of seven video consultations and three face-to-face consultations, as listed in Table 4-1. (Appendix A.4 presents the observation guide used for data collection.) All observations were conducted from the clinician's end without causing any interruptions to the ongoing session. During a consultation, I took shorthand field notes to quickly capture the events unfolding in the session, e.g., the arrangement of the room and participants at different times and the activities and conversations between the participants. This means that field notes were taken in the form of bullet points, quick sketches, and timestamps with little details on how events occurred. All the notes were manually taken in a notebook. I made significant use of sketches to take notes related to the bodily information such as the orientation of different participants, which was otherwise difficult to capture in text. The sketches not only made the data collection easier, but it also made participants relaxed with the data collection. For instance, participants could easily have a quick glance at the sketches to check what I was capturing. This, in turn, helped me in building trust with the clinicians as they felt assured that I was not taking notes related to the specificity of the patient's condition or any other private data from the patient's record. Appendix A.5 shows examples of short notes taken during the session. I also took photographs of the room to capture a visual memory of the consultation room.

Immediately after the consultation, I worked on developing elaborated notes of my observations. I sat in a quiet place for a couple of hours to write the description of how the session unfolded and what activities occurred at what time. The short-notes taken during the session and the photographs of the rooms jogged my visual memory and helped me in recalling the events post session. Again, the detailed notes were developed in a notebook and included texts and sketches. I used different colored pens to write these notes, to highlight interesting events of the session. I started coding the data as I was writing by highlighting the key incidents with a pencil. Appendix A.5 provides a description of how the elaborated notes were developed after the session and how the notes were coded during the writing process. These detailed notes became the starting point for the data analysis.

Informal Conversations

Besides observations, I utilised informal conversations to collect data during the session. I capitalized on every opportunity to have informal chats with participants to reflect upon the latest event in a think-aloud manner. With physiotherapists, I initiated conversation while they were setting up for the consultation, resolving technical issues during the session, and when the session was over. Similarly, I had informal conversations with patients and caregivers when they were waiting for the clinician in video and face-to-face consultations, or while they were leaving the room after a face-to-face consultation. Conducting informal conversations with patients during video consultations was difficult, as the patients were not around to have a conversation after the consultation was over. However, in session 8, I was able to follow a short conversation with Camilla when Phil went to call the other clinician. These informal conversations lasted for a couple of minutes and were noted down as field-notes. These conversations were also elaborated immediately after the session, in the same manner as the field-notes taken from observations. (Appendix A.6 shows the transcribed conversation with Camilla.) These elaborated notes became a part of the field notes for the respective session.

Semi-structured Interviews

Finally, to understand the challenges of communicating and interpreting bodily information during video consultations, I conducted seven semi-structured interviews with physiotherapists: six with Phil and one with Paul. These interviews varied between 40-90 minutes. All the interviews were conducted at the hospital and were audio-recorded for later analysis. Appendix A.7 presents the interview guide that I used to interview physiotherapists. My aim was to interview clinicians immediately after the session to allow reflection on the events just happened in the session. However, because of the busy schedule of the clinicians, interviewing clinicians after every session was not possible. Instead these interviews were organised depending upon their availability. Additionally, I conducted three interviews with patients and carers (present together), which lasted for 20-40 minutes. These interviews were taken after the face-to-face consultations, when patients were waiting for their subsequent consultation with another clinician. These interviews were taken outside the consultation room in the waiting area and were audio-recorded for analysis. It was challenging to interview patients and carer during video consultations, as the patient would disconnect the call right after the consultation.

Immediately after the interview, I developed a summary of the main points discussed in the interview in my field notes diary. Developing handwritten notes was particularly helpful for those interviews that involved conversations related to bodily information (e.g., angular movements) because bodily aspects were easy to draw in a notebook. (Appendix A.8 shows an example of how interviews around bodily communication were summarised in a notebook after an interview. The extract is from an interview with Phil, where he described the type of physical examination that is feasible in face-to-face consultations but not in video consultations.) While transcribing the interviews on the notebook, I highlighted the key points of the discussion with a colored pen or pencil. On the other hand, I manually transcribed the audio recordings of the interview on a computer to get the exact quotations of the participants. The transcription process allowed me to connect with the data and to simultaneously develop themes and ideas related to the collected data. I made notes of my reflection in the digital copy itself. The digital copy of the transcribed interviews was printed to develop codes. Both the interview summary and the transcribed interviews became a part of the data analysis.

4.4.4. Data Analysis

The data analysis was aimed at developing an understanding of the challenges faced by physiotherapists in understanding bodily information during video consultations. In order to describe the challenges, it was essential to provide a detailed narration of what bodily information is important in video consultations and how the role of different bodily information change over time, what activities do patients and physiotherapists perform during video consultations and how does bodily information play out in these activities. I therefore analysed the data to generate a descriptive account of video consultations.

Analysis was conducted on the following data generated from the fieldwork: (1) ten field notes scripts from visits to video and face-to-face consultations including both observations and informal conversations, and (2) ten interview transcripts along with the short summaries developed in the notebook. I employed thematic analysis (Braun and Clarke, 2006) to analyse this data, where the analysis started right from the day of data collection. I used both inductive and deductive approaches to analyse the data. The different phases of thematic analysis were not strictly followed, rather were loosely followed to generate themes and sub-themes.

Manual Transcription to Get Familiarised with the Data

The first phase of familiarisation with the data happened along with the data collection phase when I transcribed the collected data as field notes and interview transcripts. All the data was transcribed manually either in a notebook or on a computer. Although manual transcription took a significant amount of time, it provided opportunities to reflect on the study sessions and to better understand the research context. As described earlier, I generated initial ideas as I was transcribing the data.

Analysing the Data Inductively to Generate Initial Codes

Given the broad aims of the study in the beginning, at first, I utilised an inductive approach to understand the context and to allow themes to emerge. After each session, I wrote a summary of the key highlights from the session to familiarise myself with the context and to develop my assertions. Through this exercise, I started understanding the underlying technology, arrangement of the room, roles and contributions of different users (patients, carers, and clinicians), and types of communication and interactions including both verbal and non-verbal communication. I coded this summary to highlight the interesting events.

My analysis at this stage was sensitised from different theoretical concepts including user experience, proxemics, micro-mobility and f-formations. However, none of these theoretical concepts was sufficient to illustrate the dynamics of the consultations. For instance, the data had snippets of spatial arrangement between participants (Proxemics & f-formations) and examples of arrangement of technology (micro-mobility). But these patterns were not sufficient to describe the interactions between patients and clinicians. On the other hand, user experience was not very relevant in this context to understand the challenges as the underlying systems were very basic involving video conferencing software and hardware, and the participants had already adapted to these systems. More interesting was the activities between patients and physiotherapists such as exercises practised in the sessions, information that physiotherapists were looking to assess patients, and the way physiotherapists examined the patients throughout the session. I was therefore in search of a theoretical concept that can offer a language to describe these activities.

Referring to the Literature to Define Themes

I referred to the existing literature on clinician-patient interactions for clinical consultations to define themes. This helped me to obtain a vocabulary of how to define the clinician-patient interactions for physiotherapy related consultations. The existing works (e.g., (Heath, 2002, 1986)) provide a detailed account of nonverbal communication and the wide variety of activities that clinicians and patients perform at different times in face-to-face consultations. These are explained as six phases of consultations, namely, Opening, History Taking, Examination, Diagnosis, Treatment and Closing (refer Section

2.2.1 for the description of phases). All these works mainly utilise nonverbal communication to illustrate the verbal discourse between patients and clinicians, for example, the importance of eye contacts, touch and facial expressions, which however, was not sufficient for describing the insights gained from this study. Although these works became a motivational anchor for my data analysis, I was still looking for a broader theoretical concept through which I could also describe the nonverbal aspects related to body movements that physiotherapists not only observe but also describe verbally to guide the patients.

I continued with this process of iterative data analysis and referring to the existing literature to better describe the study findings. I iteratively revised the interview guide and observation guide based on my emerging understanding of the clinician-patient interactions in general and the activities of video consultations. After a couple of sessions, I also started to find patterns of different phases in my observations. Hence, I started coding the data around these phases. And during this process, I was using both inductive analysis to allow themes to emerge and deductive analysis to understand how to describe the study findings through different lens such as clinical phases. The emerging trends and themes were regularly discussed with my supervisors to reflect upon the data. Besides, I also used Member Checking (Cho and Trent, 2006) to validate and get feedback on the emerging themes from the participating physiotherapists.

Analysing the Data Deductively to Define Themes

The next phase of thematic analysis included naming and describing themes. This phase happened only towards the end of the data collection when I came across the concept of bodily communication (Argyle, 2013). Bodily communication includes a wide range of non-verbal bodily cues that a person communicates both intentionally (e.g., verbally) and unintentionally (refer Section 2.3 for more details). Although the concept is utilised to illustrate human discourse, it provides sufficient flexibility to add new bodily information related to body movements and other activities of physiotherapy consultation. I adopted this concept to describe the activities of patients and physiotherapists in video consultations, and developed a vocabulary of bodily information that I could refer to consistently to describe the findings (refer Table 2-4 in Section 2.4.1). Later, I analyzed the data with the lens of bodily communication to identify patterns of bodily cues during video and face-to-face consultations.

Based upon the relevance of bodily cues at different times of a consultation, I structured the key ideas across six known phases of a clinical consultation: Opening, History Taking, Examination, Diagnosis, Treatment, and Ending. I utilised different phases of a consultation to generate detailed understanding of what and how different activities between physiotherapist and patient unfold at different times in physiotherapy related video consultations. Also, these phases provided a structured approach to understand how the activities in video consultations are different from face-to-face consultations and where the video technology is lagging in terms of supporting the tasks of physiotherapists. Also, through these phases, it became easier to correlate the relevance of different bodily cues with different activities of physiotherapists and to examine what bodily cues are supported by video technology. In addition to these six phases, I also added another phase called Waiting phase, which describe activities of participants before the start of the session. These seven phases then became the main themes to discuss the findings. I then listed the activities that participants performed across seven phases and what bodily cues were used to perform those activities individually for both types of consultation (face-to-face and video). (Appendix A.9 shows the list that I generated during this phase of analysis, summarising phases, activities of participants and key bodily cues that were required to perform these activities. This analysis provided pointers to write the findings in detail.)

Defining Sub-themes in Writing Phase

By now the themes were defined, however, the sub-themes related to the challenges faced by physiotherapists during video consultations were not defined yet. These sub-themes were defined directly during the write-up phase of the findings. I started writing the findings from the summary of activities generated for both face-to-face and video consultations across seven phases. Using this list, I compared the activities of face-to-face with video consultations to highlight differences in activities and bodily information. Based upon the frequency of the codes and the relevance of activities to physiotherapists, I defined nine sub-themes that describe the challenges of physiotherapists in understanding bodily communication in video consultations. The main themes were also revised. I removed the Waiting phase as the activities listed in this phase were actually the challenges of the Opening phase in video consultations. Additionally, I combined the Examination and Diagnosis phases because all the consultations in the study were organised for chronic pain patients who were already seeing the physiotherapist for a couple of months (or years). In this regard, all consultations were follow-up sessions with existing patients. Hence, the main themes were reduced to five in number, namely, Opening, History Taking, Examination & Diagnosis, Treatment and Ending.

The last iteration of the findings happened during the write-up phase of this thesis when I finished data collection for all three studies. Having finished the other studies, my understanding of bodily communication and video consultations developed further, and I analysed the data more critically. At this time, I paid more attention on making a coherent story throughout the three studies. Consequently, I added one more challenge (C2), as it was observed in Study 3 and had changed the course of the study (more details are provided in Chapter 7). Additionally, I revised the language of the bodily cues to develop a vocabulary, which was also used in Study 3. And finally, I added another theme on 'Technical Issues' to highlight technical difficulties faced by the participants during this study. Next, I discuss the study findings across six themes: Opening, History Taking, Examination & Diagnosis, Treatment, Ending and Technical Issues.

4.5. Findings

Below I discuss the challenges of bodily communication in video consultations. Each challenge is numbered as C1, C2 etc. Within each challenge, I first narrate how bodily information was used in face-to-face consultations, and then I contrast it with video consultations. Table 4-2 lists the different bodily cues that were communicated across six phases of face-to-face and video consultations. Technical issues faced in the sessions are described under a separate heading. Also, I have used stick diagrams to illustrate the study findings. Key persons, such as the patient and physiotherapist in the image are highlighted in blue. All these images are created from the field notes as the consultations were not video recorded.

Phase 1: Opening

This is an introductory phase, where the patient and clinician aim to establish a rapport. In this phase, physiotherapists checked for the following bodily cues of the patient: movement patterns, quality of movements, body posture, spatial arrangement, body orientation and appearance.

C1: Limited Availability of Incidental Cues

During face-to-face consultations, physiotherapists started their examination from the moment they see the patient as they walked into the consultation room. They checked many bodily signals related to walking, sitting, and talking style that patients communicated unconsciously. For example, in session 2 (face-to-face), Phil noticed that for the entire session, Anna sat leaning forward with her arms tightly interlocked around her ribs. Her body posture indicated the pain severity in her ribs and her strategy to manage the pain by continuously pressing the ribs. Similarly, in session 7 (face-to-face), Phil noticed that Laura did not rest her feet on the floor, and positioned her feet away from each other with only toes touching the floor (refer Figure 4-2a). This body posture illustrated Laura's strategy to manage her ankle pain by bearing less weight on the affected foot, especially on the heel. Physiotherapists also checked how the patient took their seat e.g., was the patient hesitant in sitting down because of pain. Furthermore, they checked the orientation and spatial arrangement of the patients with respect to others e.g., if they preferred to sit closer to their mother or father. From these observations, physiotherapists gained information related to the behavioural and emotional state of the patient.

Phase No.	Phases	Bodily cues available in face-to-face	Bodily cues available in video consultations
1	Opening	1. Movements (walking, sitting) 2. Quality of movements (hesitation) 3. Characteristics of movements (weight distribution) 4. Posture (**full body**) 5. Spatial arrangement (w.r.t. others) 6. Orientation (**full body**) 7. Appearance (**full body**)	1. N/A 2. N/A 3. N/A 4. Posture (**upper torso**) 5. Spatial arrangement (w.r.t. others and **webcam**) 6. Orientation (**upper torso**) 7. Appearance (**upper torso**)
2	History Taking	1. Movements (exercises) 2. Quality of movements (fatigue) 3. Characteristics of movements (range of movement, **weight distribution**, **depth of squats**) 4. Posture (full body) 5. Spatial arrangement (w.r.t. **others**) 6. Eye contact (for encouragement) 7. Facial expressions **(tears, redness on cheeks**, tensed eyes) 8. Tone of speech (heaviness) 9. N/A	1. Movements (exercises) 2. Quality of movements (smoothness) 3. Characteristics of movements (**range of arm movement**) 4. Posture (full body) 5. Spatial arrangement (w.r.t. **webcam**) 6. Eye contact (**willingness to engage**, for encouragement) 7. Facial expressions (tensed eyes) 8. Tone of speech (hesitation, pitch) 9. Hand gestures (to describe pain)
3, 4	Examination & Diagnosis	1. Movements 2. Posture (**full body**) 3. Touch (**to patient body**) 4. Tactile information (body tightness, inflammation, skin temperature)	1. Movements (**through instructions**) 2. Posture (**upper torso**) 3. Touch (**to own body**) 4. N/A

		5. Response to touch (fear, protective spasm) 6. Pain characteristics (**applied pressure, pain location**)	5. N/A 6. Pain characteristics (**partially known**)
5	Treatment	1. Movements (**wide variety**) 2. Quality of movements (fatigue) 3. Posture (full body) 4. Spatial arrangement (w.r.t. others) 5. Facial expressions (tensed eyes) 6. Touch (**to patient body**) 7. Tone of speech (emphasis) 8. Hand gestures (to own body and **patient body**)	1. Movements (**limited**) 2. N/A 3. N/A 4. N/A 5. N/A 6. Touch (**to own body**) 7. Tone of speech (emphasis, **low pitch**) 8. Hand gestures (to own body)
6	Closing	1. Movements (walking) 2. Quality of movements (hesitation) 3. Posture (full body) 4. Facial expressions 5. Tone of speech (confidence)	1. N/A 2. N/A 3. N/A 4. Facial expressions 5. Tone of speech (**limited**)

Table 4-2: Bodily cues were communicated differently across 6 phases of the face-to-face and video consultations. Text written in bold indicates the difference in bodily cues, while the text 'N/A' signifies the absence of a bodily cue.

On the other hand, in a video consultation, the physiotherapist saw the patient directly sitting in front of the camera. Consequently, physiotherapists failed to see some crucial bodily movements of the patients related to their walking and sitting style, e.g., foot arrangement while talking. However, physiotherapists then utilized other cues that were available over video such as upper body posture and orientation, to understand emotional and physical state of the patient. For instance, in session 9, Jenny sat in a way that she could see Peter (over video) but not her mother (sitting next to her), as she had her back towards her (Refer Figure 4-2b). Jenny's body orientation illustrated the emotional struggle between Jenny and her mother. Peter picked up this cue and tried to make Jenny aware of her responsibilities towards her parents.

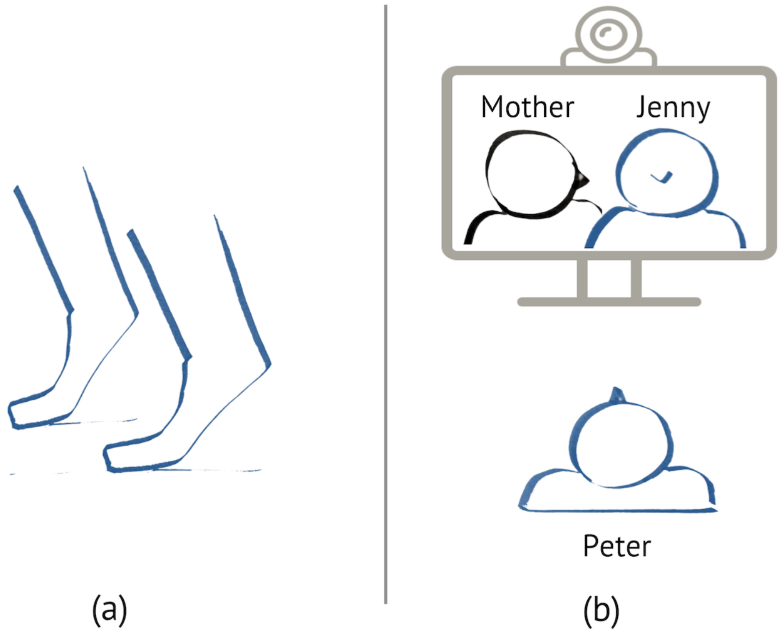


Figure 4-2: Physiotherapists observed the patient's body arrangement to understand their emotional and physical condition: (a) Phil observed Laura's lower body arrangement in the face-to-face consultation (session 7), (b) Peter checked Jenny's upper body arrangement in the video consultation (session 9).

C2: Involving Multiple Clinicians was Challenging

Face-to-face consultations typically involved 2-4 clinicians from different disciplines (refer Table 4-1). These clinicians participated in the session to have a better understanding of the patient's condition and to formulate a cumulative assessment afterwards. The involvement of different clinicians and the structure of these consultations varied. For instance, session 7 (face-to-face) was mainly driven by the physiotherapist, as the pain consultant and trainees mainly observed the session and contributed little to the conversation. At other times, the session started with a group discussion with different clinicians equally participating, and after a while, the attendees divided into smaller groups and joined again towards the end. This was seen in session 2 (face-to-face) with Anna. After having the group discussion, her parents followed up separately with the psychologist and Anna continued her session with Phil. Later everyone gathered again in the same room. Additionally, the spatial arrangement of participants changed throughout the sessions in order to allow different activities. Figure 4-3 presents the spatial arrangement of people in session 2, where everyone organised themselves in a defined circle at the beginning of the session.

However, managing multiple clinicians in video consultations was challenging. Video consultations typically involved 1-2 clinicians (as shown in Table 4-1). The session was mainly driven by one clinician and the other clinician joined in the session only for a

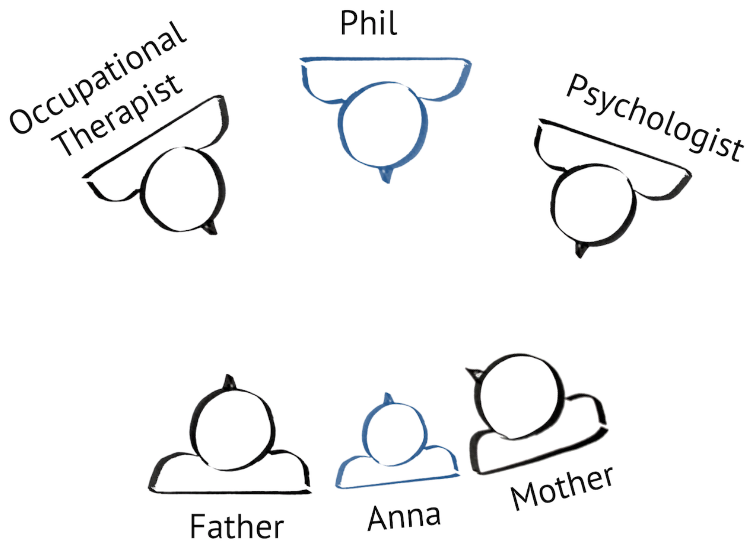


Figure 4-3: An example of the spatial arrangement followed by the participants in face-to-face consultations.

short while. Clinicians took defined turns to talk to the patients. While one clinician was talking to the patient, the other clinician showed their availability by being in the camera range either partially or fully. Clinicians arranged themselves either side-by-side to each other or in front and back position to show their availability, but did not interfere in the conversation of the other clinician and patient at any time. For instance, in session 1 (video consultation), the pain consultant joined the session only for the first 10 minutes. And when the pain consultant was talking to Anna, Phil was partially visible in the webcam (refer Figure 4-4a). Similarly, in session 6 (video consultation), the occupational therapist joined in the session for a short while, and she arranged herself at the back of the room to maintain her visibility in the webcam (refer Figure 4-4b). Whenever the multi-disciplinary team of clinicians wanted to perform a cumulative assessment of the patient, they scheduled the next session as face-to-face consultation.

C3: Limited Opportunities for Small Talk

I found that during face-to-face consultations, physiotherapists tried to build rapport with patients by initiating small talk around different topics such as weather, journey and their appearance. Physiotherapists introduced most of the informal conversation when the patient was entering or settling down in the consultation room. Having small talk not only helped the patient to open up with the clinician, but also helped physiotherapists to understand the patient's emotional state. For instance, in session 3 (face-to-face), Phil gave Anna a compliment on her new hairstyle and they started to talk about her earlier hairstyles. Anna described how she changed her hair-style using hand gestures to show hair length, *"I do a change every time my pain gets severe. Earlier I had very long hair, then it was medium and now it is very short."* With this conversation, Phil understood

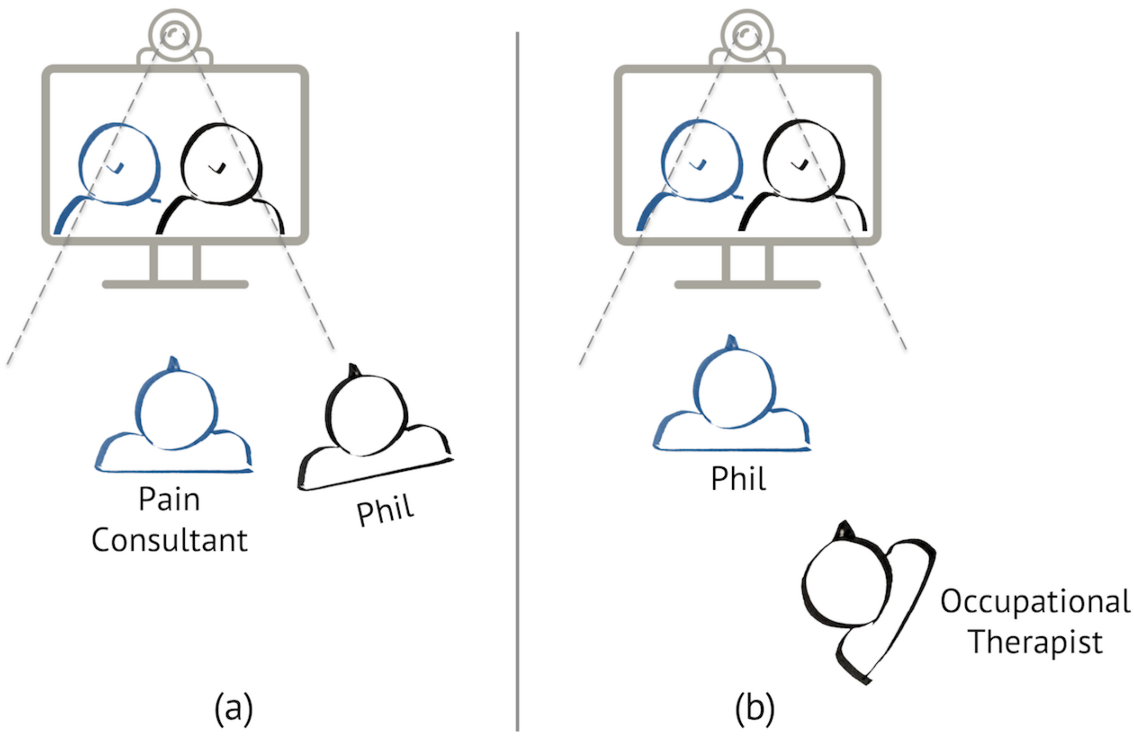


Figure 4-4: The spatial arrangement of the clinicians in video consultations: (a) Clinicians arranged themselves side-by-side, or (b) behind each other to show their availability to the patient.

that Anna's pain had not changed much since the last consultation, and that she was using different strategies to overcome her pain. Similarly, during session 7, the pain consultant invoked conversations around Laura's height by saying, *"Laura, have you grown up a bit? You look tall today."* Everyone started having a cheerful conversation on how she was looking in her last visit.

However, during video consultations, as everyone had already taken up their seats, there was a sense that clinicians should directly discuss the purpose of their meeting. Additionally, as the complete view of the patient was not available, physiotherapists did not get sufficient cues related to body movements, or full body appearance of the patient to spontaneously introduce small talk. Moreover, instead of having informal conversations, the video consultation started by making sure that the technology was working properly. And if there were issues, physiotherapists had to make alternative arrangements. Consequently, physiotherapists remained occupied and stressed in the beginning of the session, which, in turn, did not leave sufficient room to introduce small talk. However, physiotherapists tried to create a friendly environment by making jokes around the technical issues. For instance, in session 6 (video), Phil realized that there was a delay in the video streaming at Anna's end. He then responded, *"Now if I tell you a joke, I will have to wait for a while to hear the laughter."* At other times, clinicians inquired about the technical issues in a funny way. For instance, in session 8, the telehealth manager asked Camilla about the video quality by saying, *“How clear is the video? Can you see the wrinkles on my face?”*.

Phase 2: History Taking

In this phase, patients described their recovery from the last consultation, and performed different exercises. In this phase, the following bodily cues were found to be important: movements during exercises, fine-details related to the movements, quality of movements, body posture, spatial arrangement, eye contact, facial expressions, tone of speech, and hand gestures.

C4: Reliance on Verbal Explanation to Understand Symptoms

During face-to-face consultations, clinician looked for different bodily cues that patient communicated while describing their symptoms. Phil explained that since pain is subjective, descriptions of the same symptoms vary for different people. As a result, physiotherapists give more emphasis to patient’s bodily information than their verbal explanation. For instance, in session 2 (face-to-face), when Phil asked Anna about her pain, she said, *“Not so good”*. She could not say anything more as she got overwhelmed. Her cheeks turned red, her eyes were filled with tears, and her tone suddenly became heavy. Through these nonverbal cues, Phil understood that her pain severity has not changed much. However, the fine-grained details of the patients’ facial expressions and other bodily cues were not always available over video. Physiotherapists therefore primarily relied on the verbal explanation of the patient (or caregiver). For instance, during session 1 (video), Anna described her pain as *“fifty-fifty”*. She did not say anything else, but looked down. Anna’s mother picked up the conversation from there and described her pain symptoms with hand gestures. She moved her left hand up and down with great intensity and high frequency, to illustrate her pain sensations as stabbing pain. Although her hand movements did not completely fall in the camera range, Phil got a fair understanding of Anna’s health through the verbal explanation and hand gestures of her mother.

This limitation of video complicated the situation for patients who were not good at explaining things verbally. For instance, Laura was very shy and never participated in any conversation with Phil. Her expressions were always limited to binary answers on whether she was having pain in certain body parts or not. Phil, therefore, relied on her mother’s verbal description. Although Laura’s mother did a good job in describing her health issue, Phil always missed the subjective information from Laura, e.g., what exercises were helping her, and what was the improvement in her movements and pain intensity. Phil described that her improvement was so slow and so little, that it could hardly be seen over video. As a result, Phil was reluctant to see Laura over video and wanted to see her in face-to-face setting instead to better understand her recovery through other bodily information such as body language.

C5: Inability to Control Field-of-view Caused Awkwardness to Patients

During face-to-face consultations, patient showed a variety of exercises that they had been following from their last consultation. For instance, in session 7 (face-to-face), Laura performed a range of exercises that required her to lie down on the plinth and on the floor. Figure 4-5 shows some of the exercises performed during face-to-face consultations that required the patient and physiotherapist to adjust their spatial arrangement. Additionally, patients performed these exercises by taking off their shoes and socks. While the patients were performing the exercises, clinicians encouraged them by maintaining constant eye contact. At times, they also performed exercises with patients to make them comfortable. For instance, in session 7 (face-to-face), Phil realized that the presence of multiple clinicians could be intimidating for Laura as she was a bit introverted. To comfort her, Phil performed many exercises with her. As Laura was doing the exercises, Phil looked for the required bodily cues to check her improvement.

In video consultations, patients did not demonstrate all the exercises they were following from the earlier consultations. Instead they performed only a few that the physiotherapists asked for. Figure 4-6 shows the commonly performed exercises during video consultations. Patients primarily performed standing exercises such as tip-toes and squats. Patients verbally described their schedule for the remaining exercises. There

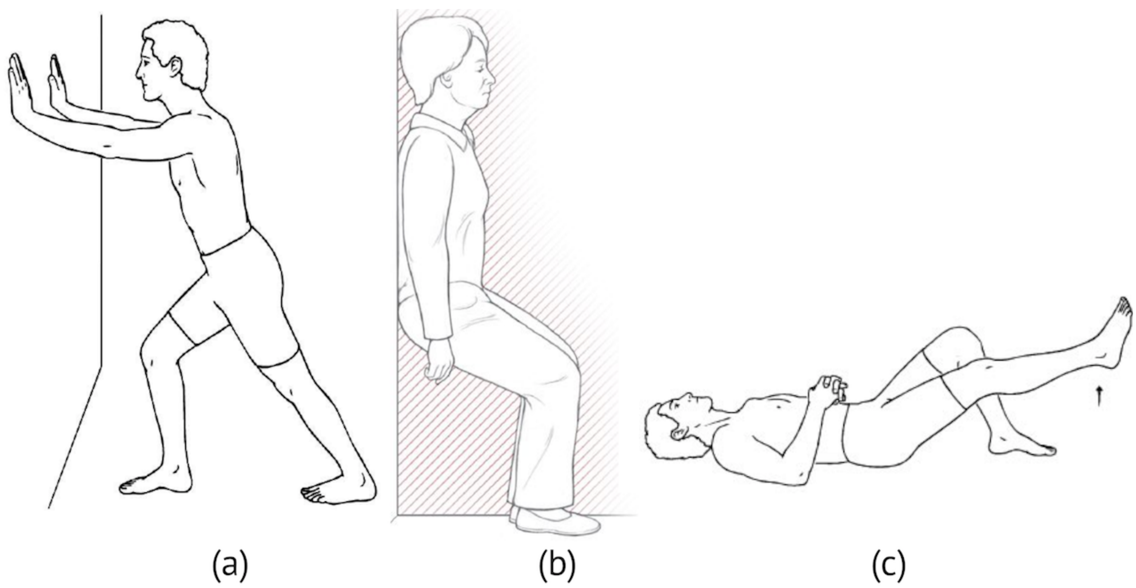


Figure 4-5: Some examples of the exercises that were performed in the face-to-face consultations: (a) knee extensions against wall, (b) wall sit ups, and (c) knee bending against wall while lying down on the floor.

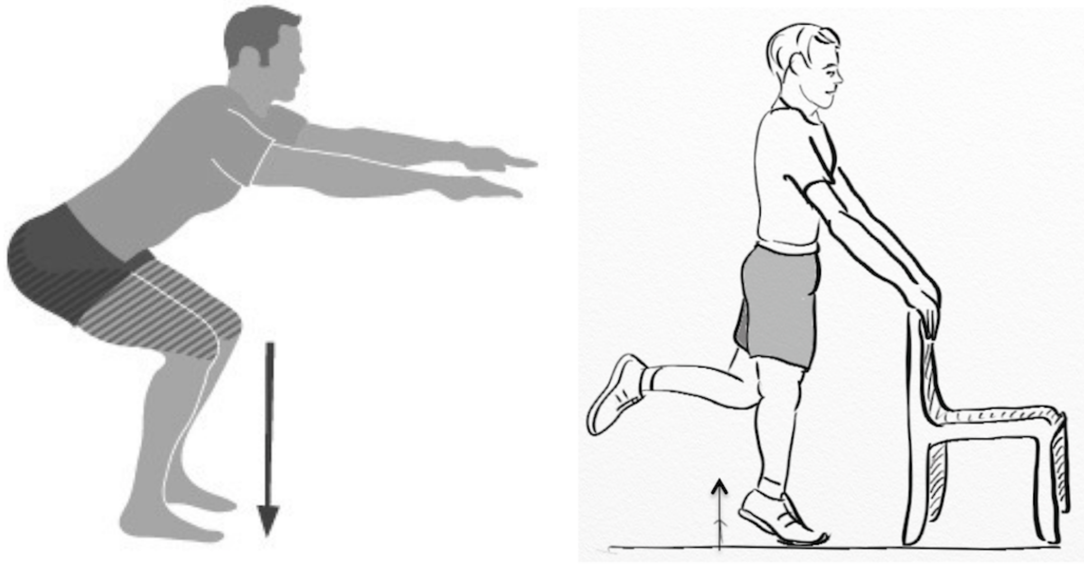


Figure 4-6: Patients performed limited exercises during the video consultations. The most common exercises performed were squats and tip-toes.

were certain instances when patients felt awkward about performing some exercises over video. For example, in session 8 (video), Phil asked Camilla to perform her shoulder exercises that required her to lie down on the bed (refer Figure 4-7). Camilla initially showed reluctance in doing the exercise and then bargained with Phil on the number of repetitions. Later in the conversation with me when we were waiting for the other clinician, Camilla mentioned that she felt awkward lying down on the bed and said that it would have been perfectly fine in face-to-face consultations. She described that the main issue was the lack of feedback from the video technology to understand her visibility on the camera, when she was at a distance from the camera. The ambiguity whether the camera was capturing her whole body or if it was more focused on certain body part made her anxious. Additionally, as she was making the video call from her bedroom in the absence of her parent, the private setting might have added more to her awkwardness.

C6: Subtle differences in Exercises were Difficult to Observe

During face-to-face consultations, physiotherapists looked for subtle differences in the exercises of the patient e.g., depth of squats, range of arm movement, and weight distribution across different body parts. To this end, they moved around the patient to understand the angular differences, or the body postures. For instance, in session 3 (face-to-face), when Anna was doing squats against the wall, Phil moved from his chair and stood sideways to see how far she was bending. For other exercises that Anna was performing while sitting on the chair, Phil corrected her back posture from tilted to

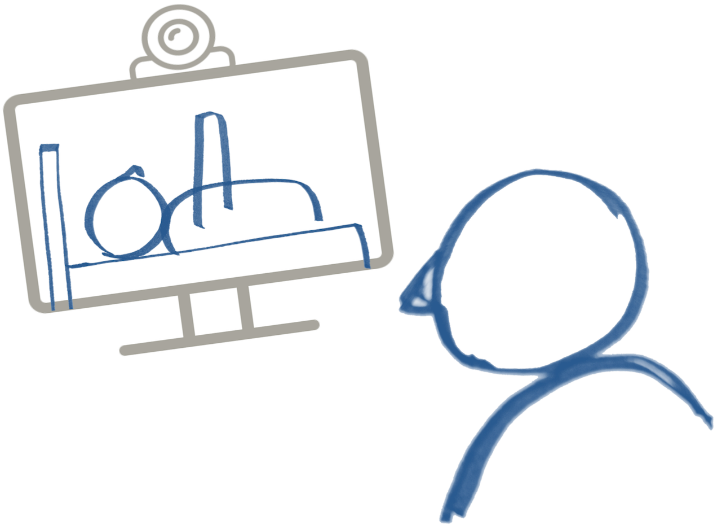


Figure 4-7: Camilla felt awkward in demonstrating shoulder exercises during the video consultation (session 8), as it required her to lie down on the bed.

straight by pressing it, as she continued with the exercise. Similarly, in session 7 (face-to-face), when Laura performed tiptoes, Phil checked the strength in her legs by observing shivering (fatigue) and weight distribution over feet.

However, over video, observing subtle differences in the exercises was not straight-forward for the physiotherapists. Most of the times, patients changed their camera arrangement to communicate the required information to the physiotherapist. For instance, in session 8 (video), when Camilla was showing the shoulder and hand exercises by lying down on her bed, Phil wanted to check the range of her hands and shoulder movements. However, he could not get that information as Camilla's laptop (camera) was kept away from the bed. Later in the session, Phil asked Camilla to demonstrate another set of hand movements, while sitting on the chair (refer Figure 4-8). This time Phil guided Camilla about how to position the camera so that he could get a good view of her hand movements. Following the instructions, Camilla sat sideways on the chair and Phil could then see the range of her arm movement, smoothness in the movements, and her facial expressions such as eyes closed and stressed.

Checking Laura's ankle improvement over video was further challenging for Phil. Since her exercises were related to ankles, understanding the subtle differences in the movements was challenging. For instance, Phil could not discern how much weight Laura was putting on her ankle while walking and while doing exercises. Focusing the camera on her ankles was not helpful because Phil also wanted to check her full-body posture with different exercises. Consequently, Phil decided not to organize video consultations for her and rather meet her only in face-to-face sessions. However, because of the long travel distance, it was not feasible for Laura to make regular trips to the hospital and therefore Phil recommended Laura to meet a local physiotherapist.

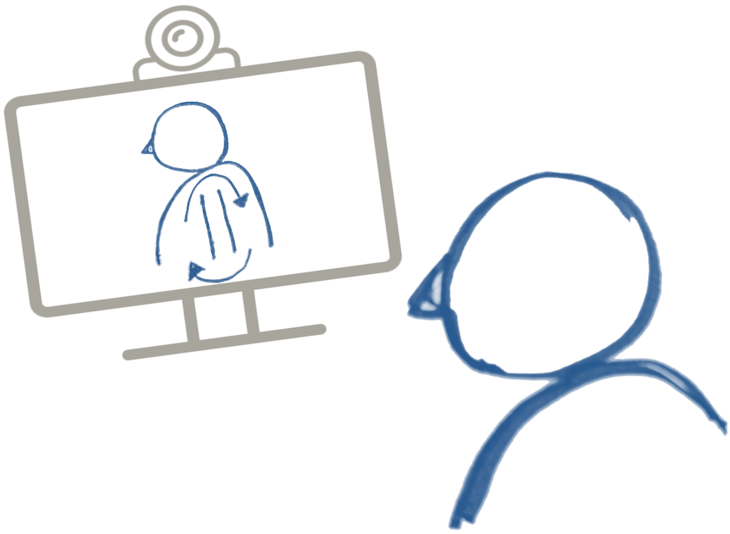


Figure 4-8: Camilla sat sideways to show the arm rolls over video (session 8).

Phase 3 & 4: Examination and Diagnosis

During these phases, physiotherapists performed oral and physical examination of the patient to assess the health issue. Essential bodily cues in this phase included body movements, posture, touch, tactile characteristics, response to touch, and pain characteristics.

C7: Hands-on Examination was not Possible

During face-to-face consultations, physiotherapists performed physical examination of the patients by pressing, touching and feeling their different body parts. For instance, in session 2 (face-to-face), Phil performed Anna's examination by lying her down on the plinth. Phil pressed the area around her stomach and ribs to figure out the location of pain. While he was pressing, Anna kept her hands near her ribs to respond to any touch that could create more pain (protective spasm). Phil inquired about the pain intensity as he continued pressing. Since Anna had inflammation near her ribs, Phil asked her to feel his ribs first and then describe the difference on her body. In this way, both Phil and Anna touched each other ribs to gain good understanding of Anna's health. Physical examination, therefore, not only provided tactile information related to the feel of her tissue (tightness), body inflammation, and skin temperature, but also provided information related to her emotional state.

As one can imagine, conducting hands-on examination was not possible over video. However, clinicians tried to conduct the oral examination whenever required in video consultations. For instance, in session 1 (video), the pain consultant asked different questions from Anna, *"Is it sensitive to touch on your body?"*, *"Is your t-shirt tolerable?"* Anna replied to these questions and verbally described her health condition. Later, Phil also orally examined Anna's pain points in different ways. In this regard, he adjusted his t-shirt to show his ribs to Anna over video and asked her to follow him from the top of her t-shirt. Following Phil, Anna pressed the area around her ribs and told him the pain points. Additionally, Phil also inquired pain location associated with different movements such as bending the neck sideways, twisting the body to one side and breathing patterns. Anna performed these movements and verbally described her pain characteristics. Although Anna followed what Phil suggested, she was afraid of touching her body because of severe pain. Also, knowing the pain points was not sufficient for Phil, as he needed other details such as how much pressure was applied to find the pain points, and how would her pain change with varied pressure intensity. Hence, he scheduled the next consultation as face-to-face, so that he could perform a fresh examination of Anna.

C8: Covert Examination was Challenging to Perform

During face-to-face consultations, clinicians often conduct covert examination of the patient by asking them to do certain tasks in the immediate environment. They interweaved such tasks within their conversation such that patients did not realize them as specific tasks. The intention behind these tasks was to check the spontaneous and unconscious reactions of the patient without giving them much time to ponder and alter their body movements. For instance, in session 3 (face-to-face), Phil wanted to check Anna's decision-making ability, as she was shortly resuming her schooling. Phil asked Anna to stand up on the plinth in the flow of their conversation. Anna thought for a while and then did not do it. Phil was happy with Anna's decision, as it could have hurt her knees. Since Phil was available in the room, it was easy for him to stop Anna if she were to try it.

On the other hand, in video consultations, physiotherapists did not have any information related to the patient's immediate surroundings. The webcam at both ends was mainly focused on the face and mainly covered the upper torso of the participants. Such an arrangement supported eye contact between the physiotherapist and patient, but restricted the physiotherapists in examining unconscious and incidental actions of the patients with surrounding artifacts.

Phase 5: Treatment

In this phase, after reviewing the patient's recovery, physiotherapists recommended different exercises to the patient. The key bodily cues in this phase were the patient's movements, quality of movements, body posture during exercise, spatial arrangement, facial expressions, hand gestures, touch, and tone of speech.

C9: Limited Scope to Recommend New Exercises

During face-to-face consultations, physiotherapists suggested new exercises to patients after seeing their progress. Sometimes these exercises were completely different from those that patients were already following, whereas at other times, they were slightly modified. The important aspect of the exercises was to follow the correct body posture to gain the necessary outcome. In this regard, physiotherapists first demonstrated the new exercise to the patient and then asked the patient to perform it together. For instance, in session 7 (face-to-face), Phil demonstrated a new exercise to Laura where he crossed his legs, and bent down to touch the floor with his hands. As Laura was following Phil, he guided her on how to maintain the correct posture (Refer Figure 4-9). Phil also laid emphasis on the correct posture by touching Laura's back and using hand gestures to describe the body parts that are under stress during the exercise. Additionally, physiotherapists also paid attention to the patient's fatigue and facial expressions to check their ability to do the recommended exercise. Sometimes, after showing the new exercises, physiotherapists also performed another physical examination to check if the exercises had caused any inflammation or increased the pain. They adjusted the intensity of exercises accordingly. Phil described that performing exercises together in this session was important as Laura was an introvert child and doing exercises in front of many people would have been intimidating for her.

During video consultations, physiotherapists were hesitant in recommending a completely new exercise to the patient, as they had limited understanding if the patient

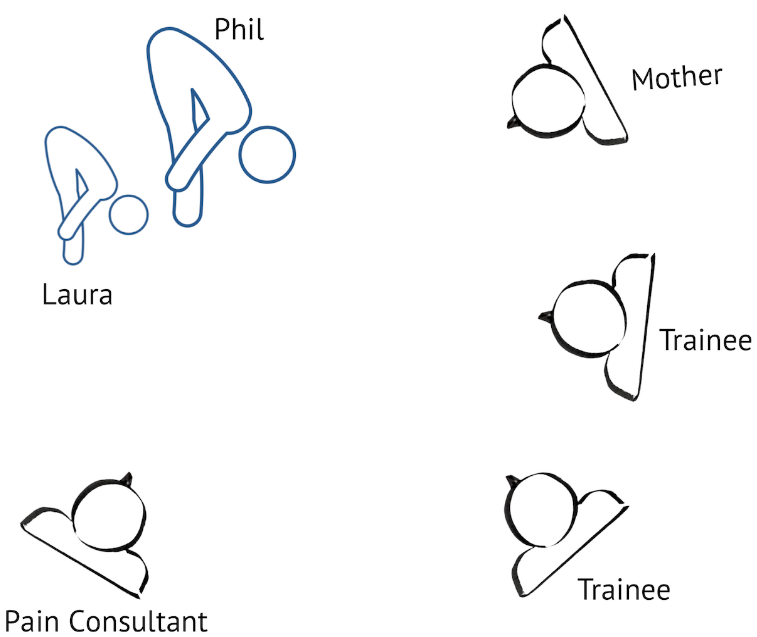


Figure 4-9: Phil also performed the recommended exercises with Laura to highlight the correct posture and to make her comfortable in front of other people.

had followed the required posture for the exercise. Physiotherapists, therefore, limited their treatment either to slightly tweaking the already suggested exercises such as changing the number of repetitions, or suggesting a very similar exercise that the patient was already following. Although physiotherapists always wanted to explain the exercises along with a short demonstration, the technical issues related to video and audio quality forced them to describe the exercises orally. For instance, after reviewing the progress of Camilla in session 8 (video), Phil wanted to show her a new exercise of standing push-ups against the wall. However, Camilla reported that Phil's video on her side was blurred. As a result, Phil verbally described the exercise and stressed the required body posture through hand gesture. Using hand as an emblem, he repeated the posture twice in a low pitch. Camilla was familiar with the exercise and thus grasped it very quickly. Phil still wanted to check her posture, therefore, asked her to demonstrate the exercise by standing against the wall. The bad video quality further restricted his ability to see Camilla's complete posture. In the end, he asked for multiple verbal confirmations to ensure that Camilla was following the correct posture and that she was not hurting herself.

Phase 6: Ending

This is the last phase where patients took leave from the physiotherapists. In this phase, physiotherapists checked the patient's movements, quality of movements, body posture and facial expressions.

C10: No Room to Accommodate Afterthoughts

To schedule the next appointment during face-to-face consultations, physiotherapists opened their calendar and shared the desktop screen with the patient (and caregiver) to find a suitable date. While discussing the possible dates, patients and caregivers often talked about their plans, which sometimes initiated new topics for immediate discussion. For instance, during session 3 (face-to-face), Anna talked about the school trip in which she was very interested to participate. Phil got a bit worried about how she would handle her pain during the trip. They then discussed strategies and developed an activity plan for the trip. Additionally, there were opportunities for patients to bring up afterthoughts of the consultation, while leaving the room. Physiotherapists also introduced small talk related to the patient's journey back home and other school activities, as they walked out of the room together. While patients were leaving the room, physiotherapists observed the patient's facial expressions and their body posture to understand their emotional state after the consultation. Phil described that when patients are happy with the consultation, they walk and talk more confidently, and smile more as they leave the consultation room.

On the other hand, the ending of a video consultation was very short and direct. Physiotherapists could not observe the patient's body posture, as everyone continued sitting in front of the camera until the physiotherapists disconnected the call. Additionally, since there was no shared calendar, both ends checked their personal calendar to schedule the next appointment. Such scheduling not only took the physiotherapist's attention away from the patient but also did not allow any new topic to surface. Finally, in the absence of any opportunistic conversations, physiotherapists vocally confirmed if the patient had any outstanding concerns to discuss.

Technical Issues

Apart from the above discussed challenges, the video consultations also involved some technical issues. Firstly, there were frequent dropouts in the video call. At other times, there were issues in the audio or visual connection. In such cases, physiotherapists used telephone to contact the patients. They discussed the issue with the patient and planned the next step. For instance, in session 6, as there were issues related to the audio connection, Phil suggested to mute the audio of the video call and use the telephone call as an alternative for audio. On the patient side, carers used their smartphone to talk to the physiotherapist during these technical issues. The mobility of the smartphone was particularly helpful in sessions where the phone call was used to make the audio connection.

Additionally, physiotherapists found it difficult to use the software, e.g., they struggled to log on to the video conferencing tool, and to find the option to initiate the video call. This difficulty in understanding the software delayed the beginning of the consultation and often the video consultations started with a delay of 10-20 minutes. In these cases, physiotherapists contacted the patient over telephone to let them know that the consultation would begin shortly. At other times, e.g., in sessions 4 & 5, physiotherapists failed in making video calls altogether because of the difficulty in understanding the software. Instead of cancelling these consultations, they carried out the consultation with the patient over telephone.

4.6. Discussion

This study illustrated that physiotherapists rely on a wide range of bodily information across different phases of a consultation. The bodily information was naturally available to physiotherapists during face-to-face consultations, however, a wide-range of bodily cues were not present during video consultations. Table 4-3 summarizes the challenges faced by physiotherapists during video consultations. Some of these cues got missed because of the different structure that video consultations follow. For instance, incidental

Phases	Challenges encountered in video consultations
Opening	C1: Limited availability of incidental cues C2: Involving multiple clinicians was challenging C3: Limited opportunities for small talk
History Taking	C4: Reliance on verbal explanation to understand symptoms C5: Inability to control field-of-view caused awkwardness to patients C6: Subtle differences in exercises were difficult to observe
Examination & Diagnosis	C7: Hands-on examination was not possible C8: Covert examination was challenging to perform
Treatment	C9: Limited scope to recommend new exercises
Closing	C10: No room to accommodate afterthoughts

Table 4-3: List of the challenges encountered during video consultations.

cues related to walking and talking style of the patient were missed (C1), as the video consultation started with patients sitting in front of the camera. Similarly, since patients continued sitting until the end of the session, physiotherapists could not understand the patient's satisfaction with the session (C10). On the other hand, some bodily cues were not available because of the limitation of video technology. For instance, subtle differences in the exercises such as depth of squats and range of movements were not distinguishable over video (C6). Similarly, tactile information related to the patient's body and their response to touch was missed because video technology does not support hands-on examination of the patient (C7).

With regards to the second sub-question (Q2), the study highlighted that lower body movements were particularly challenging to observe over video. Firstly, the webcam was focused on the upper torso of the patient, which in turn, limited physiotherapist's observations about incidental cues related to the sitting or walking style of the patients. These behaviors are indicators of patient's physical and emotional state, e.g., Laura's foot arrangement in face-to-face session (session 7) illustrated her fear of touching the affected foot on the ground. Secondly, it required different camera orientations to accurately render the depth and perspective of the patient's movements. In this regard, patients repositioned both the camera and themselves to aid physiotherapists in their assessment. At other times, patients tried to focus the camera on specific body parts, however doing so limited their ability to observe other crucial information, such as full body posture and facial expressions, that physiotherapists need to understand the patient's recovery.

Despite the webcam rearrangements that the patients made to support the tasks of physiotherapists, the subtle differences in the patient's movements were not always clear to physiotherapists. These issues together created a difficult position for Laura who was undergoing rehabilitation for her knees and ankle. Because of the challenge of understanding her slow recovery over video, Phil was reluctant to organise video consultations for her. Additionally, since Laura was living in a different city (2-hour flight journey to Melbourne), having regular face-to-face consultations with Phil was also not feasible for her. Finally, Phil recommended her to a local physiotherapist in her city.

Lack of essential bodily information influenced the ability of physiotherapists to assess and treat patients during video consultations, which answers the third sub-question (Q3). Incomplete understanding of the patient's health status reduced their confidence in assessing the patient. Consequently, physiotherapists were reluctant to introduce new exercises to patients, as they could not guarantee how accurately the patient understood the suggested activity. Instead, previous exercises were tweaked as seen appropriate. There were also instances when the patient's condition drastically changed from the previous consultation, and the partial understanding of bodily information did not allow physiotherapists to appropriately assess the ongoing health issue. In such scenarios, physiotherapists scheduled the next appointment as a face-to-face consultation, so that they could conduct the necessary physical examination to get a better understanding of the patient's health.

Additionally, there were limited opportunities to involve other clinicians in video consultations because clinicians found it difficult to manage turn-taking and to initiate group-like experience over video (C2). This, in turn, reduced the ability of clinicians to formulate the collective assessment, which is essential for treating patients with chronic pain conditions. As a result, face-to-face consultations were scheduled to understand the patient's condition. Furthermore, video consultation did not prove beneficial for patients like Laura who were shy in elaborating their symptoms and where the improvement was not noticeable over video (C4). In this regard, factors like the visibility of health issue over video and patient's ability to narrate their experience influenced the success of a video consultation. As such, video consultations were generally less specific and less targeted than face-to-face consultations.

Previous works have emphasized the need for patients to communicate essential information to the clinicians, the absence of which may reduce clinician's confidence in assessment and thereby, influencing the treatment outcome (Demiris et al., 2010; Stewart, 1995). 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). For a successful remote assessment, a clinician should get complete details of the patient's health issues, which is possible only when the patient and clinician are equipped with the right technology. This suggests the need to investigate new communication mediums that can enhance the diagnostic confidence of physiotherapists during video consultations.

In the current practices of video consultations, technology carries a strong voice with participants arranging their interactions to address the technological limitations in supporting bodily communication. Video technology further magnified the responsibilities and needs of the participants by limiting a variety of bodily cues. For instance, at the beginning of a video consultation, physiotherapists were preoccupied with making the technology work smoothly; hence, they did not get opportunities to introduce small talk (C3). On the other hand, patients struggled to get higher mobility with the underlying technology. These attempts also raised concerns at the patient end where they felt uncomfortable in performing certain types of exercises over video (C5).

In the absence of bodily cues, physiotherapists adopted new practices to obtain the required information. For instance, they introduced a show-and-tell strategy where they demonstrated different activities by referring to their body, and asked the patients to follow the actions and describe the required information. Similarly, patients changed their orientation depending upon the arrangement and capability of the underlying technology. The dominance of technology in clinical consultations has also raised concerns of depersonalizing clinician-patient relationship (Miller, 2003) and drowning out the voice of patients with technology (Storni, 2009). Future technologies for video consultations should, therefore, be designed to support the essential bodily communication so that the relationship between clinician and patient can be nurtured.

4.6.1. Design Considerations

Based on the understanding of bodily communication and related challenges gained from this study, I now discuss three design opportunities to inform the work of researchers and designers creating applications for clinical settings.

Augment the Video Medium beyond Visual Acuity

Visual acuity is the ability of our eyes to visually discriminate between different forms (Cline, 1967). In the context of physiotherapy, visual acuity is related to the clinician's ability to discern subtle changes in the exercises of a patient, e.g., depth of squats, range of arm movement, point of balance, and weight distribution (Bernhardt et al., 2002; Matyas et al., 2002). I found that during video consultations, physiotherapists could not observe the subtle differences in the exercises of the patients (C6), which were easily accessible in face-to-face consultations. Gaver explained the reason behind the limited visual acuity of video systems (Gaver, 1992). He described that the level of detail on video is always fixed at pixel size. And since video communicates high-frequency 3D information in one frame, even the sharpest pixel will only provide the structure but not the real details of the scene.

Instead of improving the visual quality of the video technology to enhance bodily communication, I suggest augmenting video consultations beyond audio-visual medium. In this regard, sensor-based technologies such as squeezable interfaces (Vanderloock et al., 2013) and wearable technologies (Norooz et al., 2015; Zhu and Cahan, 2016) have the potential to capture fine details of the patient's movements (e.g., weight distribution and range of movements). Additionally, computer vision-based systems such as Microsoft Kinect based systems (Zhang, 2012) and Vicon Tracking system (Tang et al., 2015) could also be utilized to get orientation and posture related information of the patient. The benefit of the vision-based technologies is that they provide information in abstract visualization like stick diagrams, which is particularly helpful in maintaining the patient's privacy.

Expand the Field-of-view of the Patients

Field-of-view is the extent of a physical space that can be seen at a given time. In this study, I found that the physiotherapists were restricted by the single view of the patient's space. For instance, since the webcam remained focused on the upper torso, physiotherapists could not see the patient's body language during the conversation. The single and constrained view also limited their access to patient's environmental probes, which they typically utilize to perform covert examinations (C8). Having a single field-of-view also limited their understanding of the patient's body movements; consequently, they often refrained from suggesting new exercises over video (C9).

Video consultations could greatly benefit by expanding the spatial information at the patient end. One plausible solution is to make the video call on a bigger screen with a wide-angle webcam, as earlier research showed that clinicians and patients had greater satisfaction with larger screens (Beul et al., 2011). Field-of-view can also be widened by installing multiple cameras at the patient's end, as illustrated by (Gaver et al., 1993; Johnson et al., 2015; Stevenson, 2011). However, care should be taken when presenting the information to physiotherapists, e.g., presenting raw data to physiotherapists will not only be overwhelming for them to process in real-time but could also cause discomfort to the patient as discussed earlier. One important point to note here is that having a wide-angle view does not mean that the close-up view is not important. For instance, sometimes a close view of a patient's body is of great value to get certain details like skin redness. Another approach to widening perspectives could be through different sensors that capture the bodily information which is otherwise not available on the video stream. Again, the captured data should be presented in abstract forms such as graphs or stick figures, to manage the trade-off between the clinician's information needs and the patient's comfort.

Extend the Time Sequence of Video Consultations

I found that video consultations followed a streamlined timeline where participants occupied their seat before starting the consultation and remained seated until the end. As a result, clinicians did not get incidental cues related to the patient's movements (C1) as well as their emotions after the consultation (C10). I suggest expanding video consultations in terms of the time sequence such that incidental cues become available to physiotherapists. One potential way could be to start a video consultation right from the time when the patient is getting ready for the consultation e.g., taking up their seat, or arranging the technology. This can be compared with a face-to-face visit to the hospital, where the patient spends some time in the waiting room before the consultation begins. Clinicians can observe the patient waiting or walking into the room from a distance to formulate their assessment even before the actual consultation begins. Along the similar vein, the ending phase of the video consultation could be stretched a bit longer to allow physiotherapists to observe bodily cues related to patient's emotions at the end of the session. This is similar to the ending of a face-to-face consultation, where the patient is packing up or walking outside the room as the consultation has finished, but the clinician can still observe their unconscious and incidental movements.

The important point here is that in both cases, i.e., stretching the consultation before and after the scheduled time, the video connection between the patient and physiotherapist is not required. Rather, it could only be the data visualisation from the supplementary technology, like a sensor-based wearable system worn by the patient, which is presented to the physiotherapists. To this end, designers and practitioners need to think of different ways to better support clinicians in their assessment and treatment to make video consultations more effective. Although this is more of a practice guideline than a technological implication, the technology needs to be designed carefully such that the extension blends well with the overall consultation.

4.6.2. Study Limitations

This study has certain limitations. Firstly, the understanding of bodily communication developed in this study was based on a small number of patients and physiotherapists. Additionally, although the study was conducted with two physiotherapists, the majority of the sessions were observed with only one physiotherapist. Hence, there is an issue that the study findings may not be applicable to physiotherapy video consultations in general. However, in order to make the findings applicable in other contexts, I have structured the findings around six phases of the clinical consultations and provided a detailed account of the interplay of bodily information around the clinical tasks of physiotherapists. Another limitation of the study is the credibility of the collected data, as the main source of data collection was participant observation. Hence, I may have missed out certain key activities of the session or may have misinterpreted certain bodily information, while taking notes in the session. However, in order to overcome this limitation, I followed Member Checking and validated the study findings with the physiotherapists who participated in the study. Additionally, I have provided a detailed account of the data collection and analysis processes both in the chapter and in Appendix A to make the data auditable.

4.7. Summary of Contributions

This study makes the following three core contributions:

1. This study offers the first conceptual understanding of how physiotherapists interpret and utilise different bodily information in video consultations. It provides a rich narration of the types of activities that physiotherapists and patients performed at different times during the consultation and the interplay of different types of bodily information across different phases. To this end, this study extends the literature on clinical consultations by Heath and colleagues (Heath, 2002, 1986; Heath et al., 2003; Robinson, 1998) from face-to-face consultations to video consultations, and defines the structure of physiotherapy related video consultations by employing the established phases of face-to-face consultations (Byrne and Long, 1976).

2. This study offers a rich understanding of the challenges faced by physiotherapists to understand the crucial bodily information of the patients in the current practice of video consultations. It highlights that the major issue for physiotherapists in video consultation is to understand the lower limb movements. I discuss ten key challenges faced by the physiotherapists (listed in Table 4-3) and provide details on how physiotherapists appropriate the technology to get the required information and how the inability to obtain the required bodily information limits their ability to assess and treat patients.

3. Finally, I present three design opportunities (Section 4.6) to guide the development of future video consultations systems, namely, augmenting the video medium beyond visual acuity, expanding the field-of-view of patients, and extending the time sequence of video consultations. Through these opportunities, I point to new directions that invite designers and practitioners to

utilise other computational technologies to support bodily communication in video consultations.

4.8. Conclusion of Study 1

The aim of this chapter was to develop an understanding of how physiotherapists interpret essential bodily information during video consultations, and the challenges they face in assessing and treating patients in video consultations. The study revealed that the video technology does not mediate a variety of bodily cues related to patient's movements, which limits the ability of physiotherapists to conduct remote assessment and treatment. Understanding lower body movements were particularly challenging for the physiotherapists because they require knowledge of both the full body movements as well as the specificities of the affected body part, such as the ankle. However, rendering subtle differences of the patient's movements in video consultations is challenging because of the limited visual acuity of the video technology. Also, focusing the webcam on a specific body part does not solve the problem because physiotherapists then miss other bodily cues related to the full body. Consequently, patients with lower limb issues were not considered relevant for video consultations.

Despite the challenges, the study also revealed that physiotherapists found video consultations beneficial particularly for follow-up consultations as they reduced the patients' trips to the hospital and their disruptions to schooling. Moreover, physiotherapists often switched from video to face-to-face consultations to perform timely physical examination as well as to recommend required treatment (e.g., new exercises). To this end, video consultations were not treated as a replacement for face-to-face consultations, but rather they were organized to complement face-to-face consultations. These appropriations around video consultations only emphasize that clinicians still want to continue with video consultations despite the inherent challenges. The benefits of video consultations present a pressing need to design systems that can enhance the interactions between the patient and clinician, and can better support clinicians in their clinical tasks.

After getting an in-depth understanding of the challenges faced by physiotherapists in video consultations, my next aim was to facilitate physiotherapists in assessing patients with lower limb issues during video consultations. To this end, I turned to the literature on wearable devices and other sensing technologies for rehabilitation and looked at the commercially available devices to explore potential ways of meditating bodily information in video consultations. However, since none of the existing devices fulfilled the requirement, I developed a wearable technology, *SoPhy*. I describe the development process of *SoPhy* in the next chapter.

Chapter 5
Development of SoPhy

Overview: This chapter describes the development process of a wearable technology, *SoPhy* designed to support physiotherapists in assessing lower limb issues during video consultations.

Key Publications: A small portion of this chapter is based on the following publications (listed in Appendix E.4 and E.3):
Aggarwal, D., Hoang, T., Zhang, W., Ploderer, B., Vetere, F., Bradford, M., 2017. SoPhy: Smart Socks for Video Consultations of Physiotherapy. In: Human-Computer Interaction – INTERACT 2017, Lecture Notes in Computer Science. Presented at the IFIP Conference on Human-Computer Interaction, Springer, Cham, pp. 424–428.

Aggarwal, D., Zhang, W., Hoang, T., Ploderer, B., Vetere, F., Bradford, M., 2017. SoPhy: A Wearable Technology for Lower Limb Assessment in Video Consultations of Physiotherapy. In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems, CHI '17. ACM, New York, NY, USA, pp. 3916–3928.

Public Exhibitions: *SoPhy* was demonstrated at two international academic venues:
ACM CHI 2017, Denver, USA
INTERACT 2017, Mumbai, India

5.1. Introduction

The previous chapter discussed the difficulties faced by the physiotherapists in interpreting different bodily cues related to the patient's movements that were essential for assessing and treating patients. While a wide variety of bodily information was not mediated to the physiotherapists during video consultations, lower limb issues became more challenging for them to assess over video. Motivated by the needs of the physiotherapists, I developed a wearable technology *SoPhy* that captures and mediates key parameters of lower limb movements to the physiotherapists over-a-distance. This chapter provides a detailed account of the design process involved in developing *SoPhy* with rationales behind different decisions. The design process was guided by a champion physiotherapist from the Royal Children's Hospital.

The chapter is structured as follows: The chapter starts by providing the rationale behind developing a wearable system specifically for lower limb assessment (Section 5.2). Section 5.3 states the aim of the development phase. Section 5.4 illustrates the iterative design process followed to develop a working prototype of the socks and visualisation. Section 5.5 describes the design and working of *SoPhy*. Section 5.6 discusses the implications of the design phase. Section 5.7 lists the contributions made by this chapter and Section 5.8 concludes the chapter.

5.2. Design Rationale

In this section, I discuss the rationale behind three decisions taken before commencing the development phase:

1. Rationale behind focussing on the lower limb movements during video consultations
2. Rationale behind developing a new technology instead of using an existing one
3. Rationale behind developing a wearable technology

Below I will individually describe each of these design rationales.

5.2.1. Rationale behind Designing for Lower Limb Movements

Following from the previous chapter, Study 1 highlighted that a wide variety of bodily cues were not mediated by the video technology during video consultations. However, the biggest challenge for the physiotherapists was to understand the lower limb movements of the patients over video, e.g., the physiotherapists could not understand how the patients were distributing their weight while doing exercises like squats, how far the foot was going when doing tip-toes, and what was the depth of the patient's squats. Limitations of these essential bodily cues reduced the diagnostic confidence of the physiotherapists and made their treatment less effective. Physiotherapists did not recommend new exercises to the patients because they were not confident of the patient's recovery. As such, the consultations were majorly conversational, where verbal communication became the only source to understand the patient's recovery, to examine the patient as well as to suggest treatment.

Various factors limited the physiotherapists' understanding of the patient's lower limb movements. Firstly, participants followed a different arrangement during video consultations, where the patients remained seated from the start of the consultation until the end unless requested otherwise by the physiotherapists. This arrangement restricted physiotherapists in observing the incidental and unconscious bodily cues related to the patient's walking and sitting style. Additionally, during video consultations, the webcams were focused on the upper torso of the participants. Such an arrangement further limited the access to different incidental cues related to the patients' lower limb movements, e.g., the arrangement of the feet while talking, which indicates the patient's pain intensity and fear of touching their foot on the ground. Asking the patient to rearrange the camera would defeat the purpose of this covert analysis as the patients would become conscious of their movements. On the other hand, focusing the camera on the specific body parts to render the depth and perspective of the patient's movements may appear as a good solution, however, it was also not helpful. Because doing so, limited clinician's access to other crucial information such as full body posture and facial expressions, which indicates the patient's efforts in performing the exercises. As such, assessing lower limb movements require information of both the full body movements and specifics of the affected body part (such as ankle movement). Furthermore, the camera readjustments also led to privacy concerns when the patient was not aware of the camera view on her body.

Finally, the challenge of understanding lower limb movements also emerged because of the limitations of video technology. As explained by Gaver (Gaver, 1992), video systems have a limited visual acuity. Since video presents the real-time high-frequency 3D information in the form of pixels, these pixels fail to present real details of the scene. The details presented in the pixel size is best suitable only to understand the structure of the scene rather than the subtleties. All these rationales motivated me to explore new ways to support lower limb assessment during video consultations. I was keen to explore a technology that can support the physiotherapists in understanding both unconscious and conscious movements related to the lower limb issues for effective assessment during video consultations. The important question now was to find out what parameters of lower limb movements are critical for assessment, which I describe below.

Shortlisting the Essential Lower Bodily Information

I started by examining the bodily cues related to the lower limb movements that were found limited or missing during video consultations in Study 1. I selected the following seven bodily cues - weight distribution, range of movement, foot orientation, depth, fatigue, smoothness of movement and posture (refer Table 4-2). Other bodily cues such as facial expressions, eye contact, body orientations observed in Study 1, were discarded as they were related to the upper body and were manageable over video. My design exploration was also motivated by the two design considerations discussed in Section 4.5 - *Augment the video medium beyond visual acuity*, and *Expand the field-of-view of the patients*. As such, I aimed at creating a system that could augment the visual acuity of the video technology and can provide a rich view of the patient while maintaining their privacy in order to help physiotherapists in assessing the lower limb movements over video.

After shortlisting the important lower bodily information, I then investigated the available devices that are specifically designed or can potentially be appropriated to capture details of the lower limb movements during video consultations. Below I illustrate the process of choosing the right form of technology for video consultations.

5.2.2. Rationale behind Designing a New Technology

Given the prevalence of computer vision based systems to support rehabilitation in HCI, I started by investigating the working of the existing computer vision-based systems such as Microsoft Xbox Kinect and Vicon motion tracking cameras. However, I discarded these devices because these systems have limitations in precisely capturing the subtleties of movements related to lower body (Huang, 2011; Tao et al., 2013). Another option was to install multiple cameras at the patient end and render the information to the physiotherapist. Using multiple cameras could have expanded the field-of-view of the patient, however, this option did not fulfill the other criterion on visual acuity. For instance, video recordings possess a limited visual acuity and hence, rendering subtle differences of the exercises was still an issue. Moreover, multiple cameras would have created privacy concerns for the patients, and hence I discarded the option of using multiple cameras.

Later, I turned to explore the use of non-vision based technologies such as sensor-based technologies to fulfill the aims. In pursuit, I came across to a variety of commercially available devices like pressure mats[9], Wii-Fit board[10], in-shoe soles[11] and sensing socks like Sensoria socks[12] that can potentially be used to capture the required information. However, I could not use any of the available devices because these devices only capture information related to weight distribution, and therefore required further development to capture the list of chosen bodily cues. Additionally, these systems are not specifically designed to support video consultations. Therefore, the visual output is presented locally on a mobile or a computer screen and is not available for remote access. Adopting the software according to my needs was, however, not possible because these systems either were not commercially available or did not provide open API at the time of this design phase. To fulfill the design requirements, I, therefore, decided to develop a prototype system.

After reviewing the existing sensing devices, I had a good understanding of the devices that could potentially capture details of the lower body movements. For instance, I

[9] Pressure sensing mats. https://www.tekscan.com/product-group/medical/mats-and-walkways
[10] Wii-Fit balance board. http://wiifit.com/
[11] Pressure sensing in-shoe soles. https://www.tekscan.com/applications/force-sensitive-insole
[12] Sensoria socks. http://www.sensoriafitness.com/smartsocks

understood that the required technology could be a wearable technology like sensing socks or shoe soles that a patient could wear to allow monitoring of their movements, or it could be a static device like pressure mats or Wii-Fit board that can capture patient's movements when they stand over it. The next step therefore, was to finalise one such device for the design, which would blend well with the clinical practise of physiotherapy. From my learning of Study 1, I was inclined towards developing a pair of socks, however, I wanted to validate the design choice before committing to the design process. The collaborating physiotherapist was not available at that time for a discussion. Hence, I followed an alternative approach that I describe below.

5.2.3. Rationale behind Designing a Wearable Technology

In order to choose an appropriate design from the wearable technologies and static devices for development, I conducted observations of a 2-hour practical session of the postgraduate physiotherapy students at the Department of Physiotherapy of the university. This class was focussed on lower body functioning, where physiotherapy students performed several group activities involving role-playing as patients and physiotherapists for given patient conditions. Using the think-aloud approach, I inquired the students and the instructor in the classroom about the ongoing activities to understand the setup and their actions. These observations generated the following key insights and helped me in narrowing down to designing a wearable technology:

1. Firstly, in line with the observations of Study 1, the students in this class were practicing a variety of exercises - some involved movements at a place like squats and standing on one leg; whereas others were more dynamic, e.g., walking and hopping. This confirmed my hypothesis that static devices like Wii-Fit board or pressure mats will not be able to capture and support the dynamicity of the physiotherapy sessions. Rather, devices that move along with the patient's body like sensing socks or shoe soles would be more appropriate.

2. Secondly, physiotherapists typically ask patients to perform exercises with barefoot and in some cases with socks. They do not recommend wearing shoes during exercising because shoes conceal the foot structure and therefore, do not support the visual assessment of the patient, which on the other hand, is possible in barefoot or with socks. This observation highlighted that designing interactive socks to capture the patient's movements will be more appropriate than designing a pair of shoes.

3. Finally, physiotherapists are very careful about the surface on which the patient performs exercises. They prefer non-slippery surface such as a carpeted floor to protect patients from skidding, e.g., patients may lose their balance while doing different exercises like standing on one leg or hopping at a spot. This helped me

to understand that the material of the wearable technology should be non-slippery.

Through these observations, I chose to design a pair of interactive socks as opposed to other sensing devices like shoes or mats because of the following three reasons: First, socks are lightweight and therefore, comfortable to wear while exercising. Secondly, socks conform to the body, and therefore, can precisely capture fine-details of the movements; and finally, socks move along with the patient and therefore can capture details of both the static and dynamic movements.

Designing interactive socks is, however, only one part of a system. Visualising the captured information is also critical to create an understanding of the captured data. Visualisation supports "*Seeing*" of the data and makes knowledge credible (Bloch, 2008). It helps users to discover concepts and patterns within the data that were previously unknown or only imagined (Card et al., 1999). The gained knowledge, in turn, helps the users to take the necessary steps and act accordingly. Hence, the development of a wearable system involved developing a pair of socks and an accompanying visualisation.

5.3. Design Objectives

The development phase had the following aims:

"How do we design a wearable system to help physiotherapists in assessing lower limb movements during video consultations?"

I answered this objective through two sub-questions:

Q1. How can we sense lower limb movements of the patients through a sensor embedded socks?

Q2. How can we visualize the movement data over-a-distance to support physiotherapists in their assessment?

To address the above-mentioned research questions, I employed an iterative human-centred design approach and worked with a physiotherapist (pseudonym: Phil) from the collaborating hospital, Royal Children's Hospital. The design phase was carried out with a Masters student (Weiyi Zhang) and with my supervisor (Dr Thuong Hoang) who respectively helped me to develop the web-interface and interactive socks. To guide the development of the web-interface, I provided Weiyi with the templates of the web-interface layouts and the visualisation sketches. She developed the front-end (interface) and the back-end (server) of the web-interface along with a mobile app to support the data transfer between the socks and the server. I developed the socks under the guidance of Dr Hoang who guided me with different procedures of designing a wearable technology, e.g., soldering the Arduino boards, making electronic circuits and checking the working of the sensors. All critical design decisions were taken in consultation with Dr Hoang.

5.4. Design Process

The aim of this design process was to develop a working system that can capture the lower limb movements of the patients and present the captured information to the physiotherapists in real-time during video consultations. To achieve so, I planned to design a pair of interactive socks for the patients and a web-interface for the physiotherapists to present the collected data. I employed iterative prototyping to design the system, where iterations of the socks were inspired by the aim to precisely capture lower body movements while accounting for the comfort of the patients in wearing the socks. On the other hand, iterations of the web-interface were motivated by the need to effectively present the visualisation such that clinicians can easily interpret them in real-time during video consultations. As explained earlier, seven bodily cues were selected for the design process - *weight distribution, range of movement, foot orientation, depth, fatigue, smoothness of movement* and *posture*. This list was also iteratively revised during different iterations of the prototype based on the technical feasibility to capture them accurately and their relevance for the physiotherapists. I utilised sketches to brainstorm about different possibilities for both the socks and interface, given their benefits in speeding up the ideation process (Marquardt and Greenberg, 2012; Verstijnen et al., 1998). The design process spanned over a 6-month period.

To better understand the needs of the physiotherapists and patients in using the system, I also collaborated with a physiotherapist working at the Royal Children's Hospital. Initially, I planned to conduct focused group discussions with the physiotherapists at the collaborating hospital to understand their needs as well as to get feedback on the different iterations of the prototype. However, the busy schedule of the physiotherapists limited my access. And finally, I was mainly guided by a champion physiotherapist (pseudonym: Phil) at the hospital, who was practicing physiotherapy from more than 15 years and was keen to improve the existing video consultation systems to better help his clients. He also participated in Study 1 and therefore was aware of the focus of this research from the beginning. I organised multiple discussions with him to get his feedback on different iterations of the prototype. Additionally, I also conducted informal discussions with multidisciplinary experts from the surrounding research community to get insights on the usability of the socks and interface.

Below I will first describe the discussions with the collaborating physiotherapist and the multidisciplinary experts and later will illustrate the iterations of the socks and the web-interface. The different phases of the discussions and iterations of the socks and web interface are described in a linear order for clarity, but in practice, they were conducted in parallel.

5.4.1. Discussions with the Collaborating Physiotherapist

I organised three meetings with the collaborating physiotherapist to refine the list of the bodily cues and to get feedback on the design of the socks, visualisations and overall web-interface layout. These meetings were organised depending on his availability and therefore did not follow any regular pattern. For instance, the third meeting was organised after two days of the second meeting as he was going away for a month after then. Table 5-1 provides a summary of each meeting with the physiotherapist during the iterative process of designing the prototype. I will briefly describe the discussions happened in these meetings to illustrate his contributions to the development.

The first meeting was driven by the sock sketches, where I discussed the merits of using different sensors and their placements on the sock in order to capture the required bodily cues (i.e., weight distribution, range of movement, foot orientation, depth, fatigue, smoothness of movement and posture). The physiotherapist emphasized that to capture accurate data for different bodily cues, placement of the sensors is very critical and

S.No.	Design Prototype	Topics of Discussion
1	Sock sketches	○ Relevance of the chosen bodily cues and sensors ○ Discussion on the placement of sensors ○ Discussion on different bones and muscles that drive lower body movements
2	Sock prototype and sketches of the visualisation	○ Relevance of the chosen bodily cues ○ Calibration of the sensors for different sized foot ○ Working of the human foot - movement happens mainly in the front and rear directions
3	Sketches of the visualisations and web-interface, and the sock prototype	○ Role-playing as a patient and physiotherapist to understand the use of the system ○ Discussion on improving the readability of the visualisation and web-interface layout

Table 5-1: Summary of the discussions held with the collaborating physiotherapist during the design phase.

should be considered carefully. To explain the correct positioning of the sensors, he sketched out the important bones and muscles that drive our lower limb movements (refer to Figure 5-1). His suggestion was not to place any sensors on the bones (e.g., shin bone) or in areas having high body fat (e.g., calf), as it will generate noisy data. For correct detection of fatigue, he mentioned to place the sensors on the two muscles - vastus lateralis and vastus medialis obliquuus (as shown in Figure 5-1). With regards to the weight distribution data, he suggested that the weight of a healthy person is predominantly distributed over the balls, heel and big toe of the foot. However, weight bearing on each toe might be relevant for certain patients, e.g., those having toe injuries. Following the discussion, I revised the list of the sensors and their positioning. I excluded posture from the list as it can be managed over video, and the revised list consisted of the following bodily cues: *weight distribution, range of movement, foot orientation, depth, fatigue,* and *smoothness of movement*.

In a second meeting with the physiotherapist, I discussed the calibration of the sensors for different foot sizes and for people with different body weight by showing the sock prototype. The meeting started by the physiotherapists trying out the socks and commenting on its wearability. As he put on the socks, the pressure sensors got dislocated, as the socks did not match with his foot size. This gave me the insight to prepare socks of different sizes for proper calibration of sensors. Additionally, I also discussed the relevance of the selected bodily cues, as I was facing technical challenges

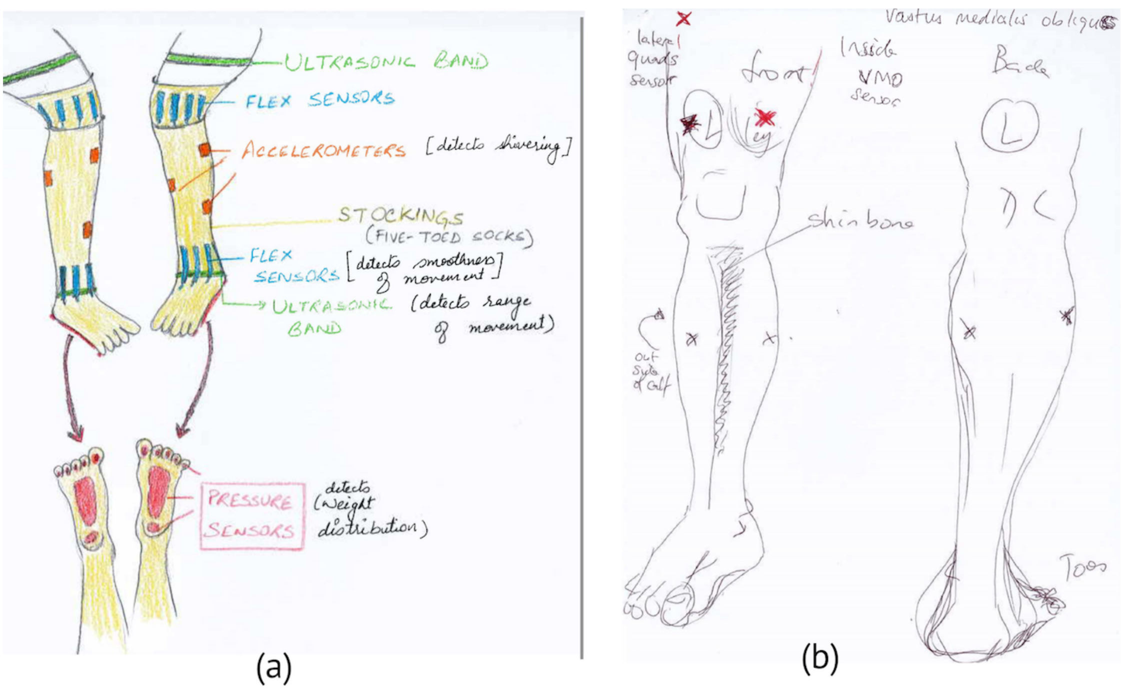


Figure 5-1: Points of discussion with the collaborating physiotherapist in the first meeting: (a) Sock sketches were used for brainstorming, (b) The physiotherapist sketched out the important lower limb bones and muscles to guide the prototype development.

in capturing some of them. He confirmed that weight distribution, foot orientation and range of movement are the key aspects of the lower body movements and visualising them would offer valuable insights that are not easily available over video. Other bodily cues such as fatigue, depth, and smoothness of the movements are dependent upon several factors and could be inferred from the key parameters. For instance, if the patient is not going low enough (depth) while doing squats, potential reasons could be muscle tightness, pain or fear – the physiotherapist will discuss the reason with the patient verbally. He also cautioned me regarding the use of flex sensors around ankle as our foot follows movements mainly in the rear and front directions with little movements on the sides. Owing to the technical challenge of capturing accurate data for fatigue, depth and smoothness of movements, I dropped these bodily cues after this discussion. Finally, the key parameters for the design iteration included weight distribution, foot orientation and range of movement.

In the last meeting, I evaluated the clarity of the visualisations and ran through the possible layouts of the web-interface with the collaborating physiotherapist. (Appendix B.1 shows the sketches of the visualisations and Appendix B.2 shows different templates of the web-interface that were discussed in this meeting.) To evaluate the utility of *SoPhy*, we role-played as a patient and physiotherapist and tried different exercises using the sock prototype and paper prototypes of the visualisations. He suggested using different colors for the visualisation, as it would be easier to talk about the movements in terms of colors as compared to numbers or size of circles. He also marked his preference for different visualisations and web-interface layouts. Furthermore, he suggested having a clean and direct visualisation without any additional animations, as the interface should only supplement the clinician's observations made through the video stream.

5.4.2. Discussions with the Multi-Disciplinary Experts

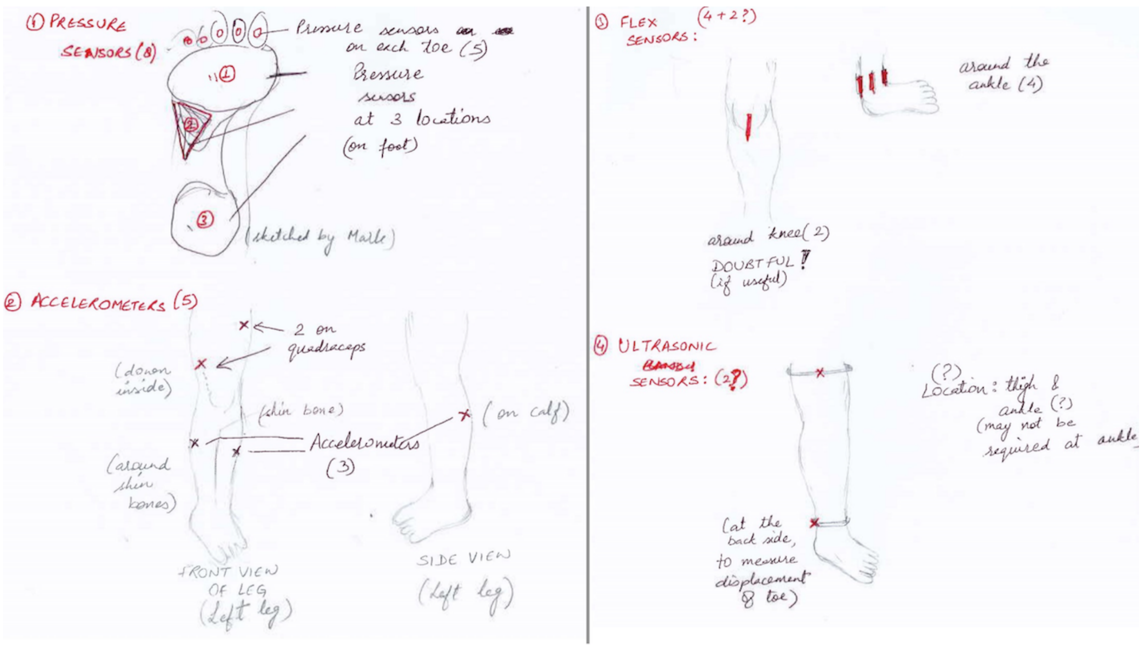
Along with the ongoing discussions with the physiotherapist, I held multiple informal discussions with experts from the surrounding research communities. These participants were from different academic backgrounds, e.g., Electrical and Electronics Engineering, Computer Science and Interaction Design. Their expertise helped me to refine the design choices in terms of the electronics, aesthetics and comfort of the sock, and the presentation of the visualisations on the web-interface. For instance, after every iteration of the socks, I ran short usability studies with the experts to find out the potential issues. These experts were asked to wear the socks and comment on its comfort and visual appeal and were also encouraged to provide any suggestions for improvements. Similarly, visualisation schemes of different sensor data and iterations of the web-interface were discussed with them to get their feedback for further improvement.

5.4.3. Designing the Socks

Designing the socks required identifying the right sensors that can capture the selected list of bodily cues - weight distribution, range of movement, foot orientation, depth, fatigue, smoothness of movement and posture. Consequently, I explored the use of various sensors such as flex sensors, accelerometers and ultrasonic band.

Prototyping began by brainstorming about the possible sensors for different bodily cues with my supervisors, which was rendered as paper-based sketches, as shown in Figure 5-1a. These sketches included details of the appearance of the socks, placement of different sensors, and number of each sensor. After having the first meeting with the physiotherapist, I revised the potential design of the socks and developed another sketch (as shown in Figure 5-2). These sketches included many sensors - seven pressure sensors, three accelerometers, eight flex sensors and two ultrasonic band on each leg. These sketches then guided the sock development.

After the ideation, the next step was to start the hardware development. Following the iterative development process, I tested the utility and working of different sensors in order to collect data related to the selected list of bodily information. The type and number of sensors changed in these iterations. The selected list of bodily cues was also refined based on their relevance and technical challenges in capturing them accurately. The final list of the bodily cues developed after the second iteration included weight distribution, foot orientation and range of movement. In total, the socks went through



(a) (b)

Figure 5-2: Revised sketch of the socks that guided the development process.

six iterations, where each iteration comprised of a sewing trial followed by a short usability lab testing with multidisciplinary experts. (Appendix B.3 provides a summary of the activities performed in each iteration.) Figure 5-3 shows the design of the three iterations and the final design of the socks. Below I enumerate different factors that guided the iteration of the socks as S1, S2 and so on.

S1: Designing for the Patient's Comfort

While iterating the design of the socks, I paid special attention on the comfort factor so that the developed socks do not add any discomfort to the patient who are already in pain. This goal created several challenges that I overcame along the way. Firstly, it affected the form of the socks. Initially, the aim was to capture pressure values on each toe to get rich data about weight distribution patterns, for which I used 5-toed socks and Flexiforce Pressure Sensors[13]. In the first iteration, I sewed four pressure sensors on a 5-toed sock – one on the big toe, two on the balls and one on the heel (refer Figure 5-3a). However, sewing pressure sensors on the small surface area of the toes and avoiding short-circuiting of the connections around LilyPad were challenging. The usability testing with experts also highlighted that the 5-toed sock prototype was uncomfortable to wear, as sewing sensors on the socks reduced its stretching capacity. This would further become a challenge for patients with swollen foot or toes.

(a) (b) (c) (d)

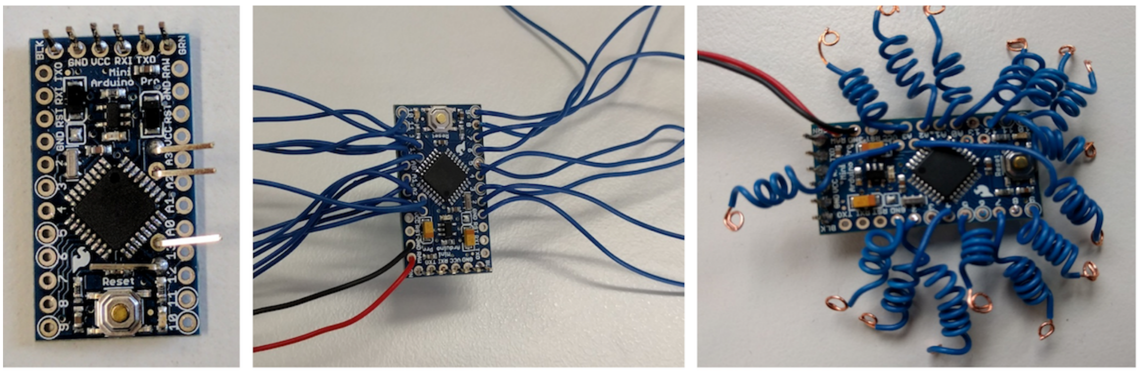
Figure 5-3: Different iterations of the socks: (a) The first iteration included a 5-toed sock using LilyPad. Later, I switched to the normal socks and used different arrangements of the conductive wires (b) and external clothes (c). The final design shown in (d) used a combination of the conductive threads and wires.

[13] Flexiforce Pressure Sensors. https://www.sparkfun.com/products/11207

Consequently, the number of sensors was reduced to three: one on each ball and one on the heel. Reduction of pressure sensors then affected the choice of the socks and I switched to using regular socks instead (see Figure 5-3d for the final design).

Secondly, the aim of developing comfortable socks also influenced the choice of electronic components that were utilised to design the socks. Consequently, certain design decisions contradicted with the principles of the wearable computers. For instance, I utilised Arduino ProMini board[14] instead of the microcontrollers like LilyPad[15] that are specifically designed for designing wearable systems. Electronic components for the wearable systems are specifically developed considering the visual appeal; however, visual aesthetics of the socks was the secondary design goal for me. For instance, in the first iteration with the 5-toed socks, I used LilyPad. However, being larger in size and having harder surface, it made the socks uncomfortable as the wearer could feel the attachment on their foot. Consequently, I utilised Arduino ProMini as it is smaller in size, and therefore, supported a compact design of the socks. Additionally, Arduino ProMini has more Analog pins to connect several sensors simultaneously.

Using Arduino ProMini however, also raised certain issues, which further challenged the notion of a wearable system. ProMini board raised the issue of short-circuiting as the pins on the board are very close to each other. Additionally, majority of the Analog pins (A4 to A7) are in the middle of the board, which made it difficult to create thread connections for the sensors. Hence, the board was altered with thin conductive wires and hard conductive pins, which offered more flexibility in making the connections. However, using such extensions again contradicted with the wearable systems, which



(a) (b) (c)

Figure 5-4: Arduino board was appropriated across different iterations to develop a comfortable pair of socks. Different types of extensions were made with the conductive pins (a) and conductive wires (b), (c).

[14] Arduino Pro Mini Microcontroller. https://www.arduino.cc/en/Guide/ArduinoProMini
[15] LilyPad Arduino Main Board. https://store.arduino.cc/usa/lilypad-arduino-main-board

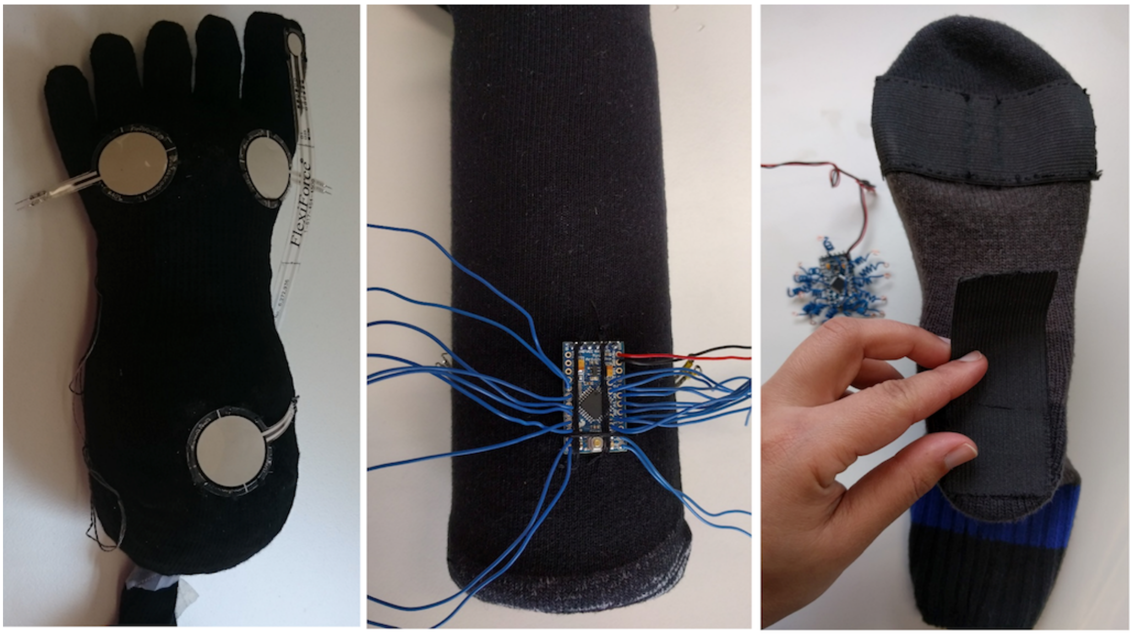
Figure 5-5: All the wired connections were hidden underneath a cloth in the final design of the socks.

are typically developed using the conductive threads (refer Figure 5-4). I tried different variations of the connections, e.g., in one of the iterations, I made direct wired connections between the sensors and Arduino board, which made the socks look bulky and less appealing (Figure 5-3b). Hence, in the final iteration, I utilised a combination of wired extensions and thread connections and hid all the wires underneath a cloth (see Figure 5-5). To get more space in making connections around the board, I moved the Arduino board on the cloth, which in turn, made the socks more comfortable as the wearer did not feel any attachment moving on their foot.

S2: Designing to Accommodate Different Foot Structure

Size of the socks is typically defined based on the length of the foot, e.g., large, medium and small-sized socks. Generally, other factors such as width of the foot and length of the toes are not considered, as the socks are stretchable to fit around different foot structure. While designing the socks, using different sized socks was not sufficient. Accommodating different foot structure became a challenge because different structure caused dislocation of the sensors, thereby, leading to inaccurate data collection. Additionally, it also led to breakage of the conductive threads when the sock was tight on the foot, which in turn, damaged the circuit connections and required a fresh sewing. Consequently, I gave special attention to keep the sock stretchable and explored different strategies to achieve so.

Firstly, I inserted different objects like Thermocol balls and a foot model to stretch out the socks when sewing the sensors (refer Figure 5-6). In the first iteration with the 5-toed socks, I utilised Thermocol balls. However, the developed sock was only suitable for a



(a) (b) (c)

Figure 5-6: Different types of insertables were used for sewing sensors on the socks: (a) Thermocol balls (b) a water bottle, and (c) a foot model.

small sized foot. Also, the Thermocol balls, being small in size, were difficult to handle, e.g., filing the balls inside the socks took a long time, which made it challenging to test the socks in the middle of a sewing trial. I then looked-for objects that were easier to remove and insert. In the later iterations, I tried using a water bottle to stretch the sock while sewing. However, using the bottle deformed the sock shape, and resulted into dislocation of the sensors from the target location. Finally, I utilised a foot model, as it provided a good estimation of the location and supported sewing of the sensors on the correct locations. Additionally, the foot model also supported easy sewing experience, as compared to the bottle or Thermocol balls.

These insertables although offered a good solution to design for different foot length, however, accommodating different foot width was still a challenge. In pursuit, I initially utilised long conductive wires to get sufficient room for different foot sizes, where the wires would stretch based upon the foot size (refer Figure 5-6b). However, using the conductive wires made the sock look bulky and less appealing. On investigating deeper, I realized that the conductive threads broke mainly when the direction of the thread was opposite to the direction of the socks yarn, e.g., making horizontal connections with conductive thread on a sock having vertical weaving created the issue. Hence, in the next iterations, I avoided making opposite connections and mainly made vertical connections with the conductive thread. To make horizontal connections, such as near to the Arduino board, I ran the stitches over an external piece of cloth and not directly on the socks. Figure 5-5 shows the connections made in the final design of the socks.

(a) (b)

Figure 5-7: Different arrangements were sought to sew the flex sensor on the socks. (a) At first, the flex sensor was sewed on the sock using the conductive thread. (b) Later, the sensor was attached on a Velcro tape to accommodate different foot sizes.

Different foot structure also challenged the calibration of the sensors. When I was using the flex sensors[16] to capture the information of foot orientation, different foot structure changed the accuracy of the data captured by the sensor. The flex sensor reading was dependent upon its position around the ankle, which was changing for different foot sizes. Using conductive wires particularly proved beneficial to capture information of foot orientation with the flex sensors. I sewed the flex sensor on the Velcro tape and connected it to the Arduino board using conductive wires (refer to Figure 5-7b). Because of the Velcro tape, I got the flexibility to adjust the flex sensor up and down based on the foot size, which was not possible to achieve with conductive threads (see Figure 5-7a).

S3: Embracing Human Anatomy into the Design

Another factor that influenced the iterations of the socks was the human anatomy, i.e., the structure and working of the human body. Understanding of the human anatomy was mainly obtained through discussions with the collaborating physiotherapist. Following his suggestions, I explored the working of the different sensors at the suggested locations on human body parts. To begin with, I captured the information related to weight distribution by attaching pressure sensors on different areas of the sole, where a healthy person bears maximum weight. In the initial iteration with the 5-toed socks, I

[16] Flex Sensors. https://www.sparkfun.com/products/10264

used four pressure sensors – two on the balls of the foot, one on the heel and on the big toe. However, as discussed above, the prototype was unsuccessful as the sock was uncomfortable to wear. Later, I switched to using three pressure sensors on three locations of the sole – two pressure sensors on the balls of the foot and one on the heel. In this regard, I successfully obtained the correct location to capture information about weight bearing patterns in the initial iterations. Therefore, the aim in later iterations was to design a comfortable pair of socks and to achieve a higher sensitivity of the sensors to accurately capture subtle differences in the movements. In pursuit, I investigated the use of different resistors and explored different ways to make circuit connections (e.g., using conductive threads and wires).

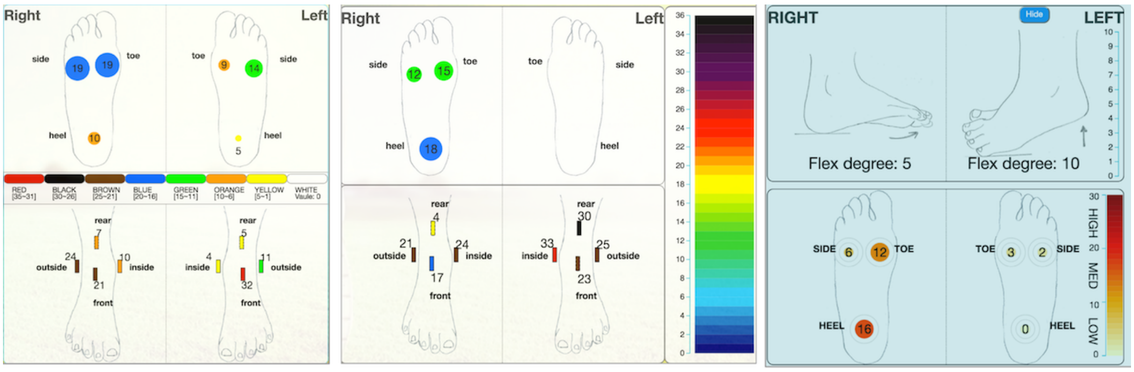
Capturing the range of movements and foot orientations, however, required multiple iterations. In the beginning, I explored the use of the flex sensors because of the ease to process the captured data. I tested flex sensors by sewing four of them on the socks around the ankle (Figure 5-3b). However, owing to the limited movements around the ankle, the flex sensor was not sensitive enough to capture the movements. For instance, the foot demonstrates major movements mainly in the front direction as compared to the other three directions. Hence, only the front flex sensor generated a good range of data. However, one stream of data was not sufficient to derive any inferences related to the foot orientations and range of movements. Finally, I dropped using the flex sensors and utilised the Adafruit 9-DOF Absolute Orientation IMU Fusion Breakout[17] sensor. The IMU sensor provides data points across xyz coordinates, which was processed to derive values of foot orientations and range of movements.

Finally, understanding the human anatomy also helped in scrutinizing the list of chosen bodily cues and the potential of different sensors to capture them. In this regard, I dropped some bodily cues like fatigue and smoothness of movements, as they are very subjective to the patient's psychological and physical health. Hence, are not possible to capture accurately through sensors.

5.4.4. Designing the Visualisation

The second part of the system was the visualisation. Developing visualisation of the data began after the second iteration of the socks, as by then I started to understand the data generated by different sensors. I utilised paper-based sketches to explore different options for the visualisation because they offered a quick way to brainstorm about the potential of different visualisation schemes with the collaborating physiotherapist and with other experts. After finalising the visualisation scheme on the paper, the accompanying web-interface was developed. The web-interface has undergone two major iterations (as shown in Figure 5-8 a & b) along with other minor changes to

[17] Adafruit Inertial Movement Unit BNO055. https://www.adafruit.com/product/2472



(a) (b) (c)

Figure 5-8: Different iterations of the visualisation: (a) The initial version used discrete colors to present data. (b) The visualisation was refined to present data using a continuous color spectrum. (c) The final iteration includes a combination of numbers, pictures and continuous color spectrum for presenting data.

develop the final iteration shown in Figure 5-8c. Below I provide an account of the factors that motivated the development of the visualisations and web-interface. I enumerate the design choices as V1, V2 and so on.

V1: Developing Visualisation in Parallel with the Socks

I kept the process of refining the socks and visualisation in parallel, as it helped me to consider the utility of the sensor with respect to the design goals. For instance, even though the accelerometer was working fine, I discarded it because it was challenging to create a meaningful visualisation of fatigue from the generated data. Similarly, I dropped using flex sensors after the fifth iteration of the socks because one flex sensor was not providing rich data to create visualisation related to the range of movement and foot orientation. For instance, through the data generated by the flex sensor, I could only develop a line-based representation with numbers changing based on the foot movements (as shown in the lower half of Figure 5-8a). The line-based representation mimicked the shape and placement of the flex sensor around the ankle. However, a single number and the changing color of the line were not sufficient to understand the details of foot orientation.

To investigate meaningful representations for foot orientation, I sketched out other possible representations on paper (as shown in Figure 5-9). These sketches utilised the data from both the flex and pressure sensors, and the foot moved with different degrees in four directions. When tested with experts, these representations were more appreciated by the experts than numbers. Therefore, through these paper-based sketches, I made the decision to opt out the flex sensor and looked for other sensors that can potentially generate rich data to create visualisations similar to the paper sketches. The interface, however, did not change further because I continued to face

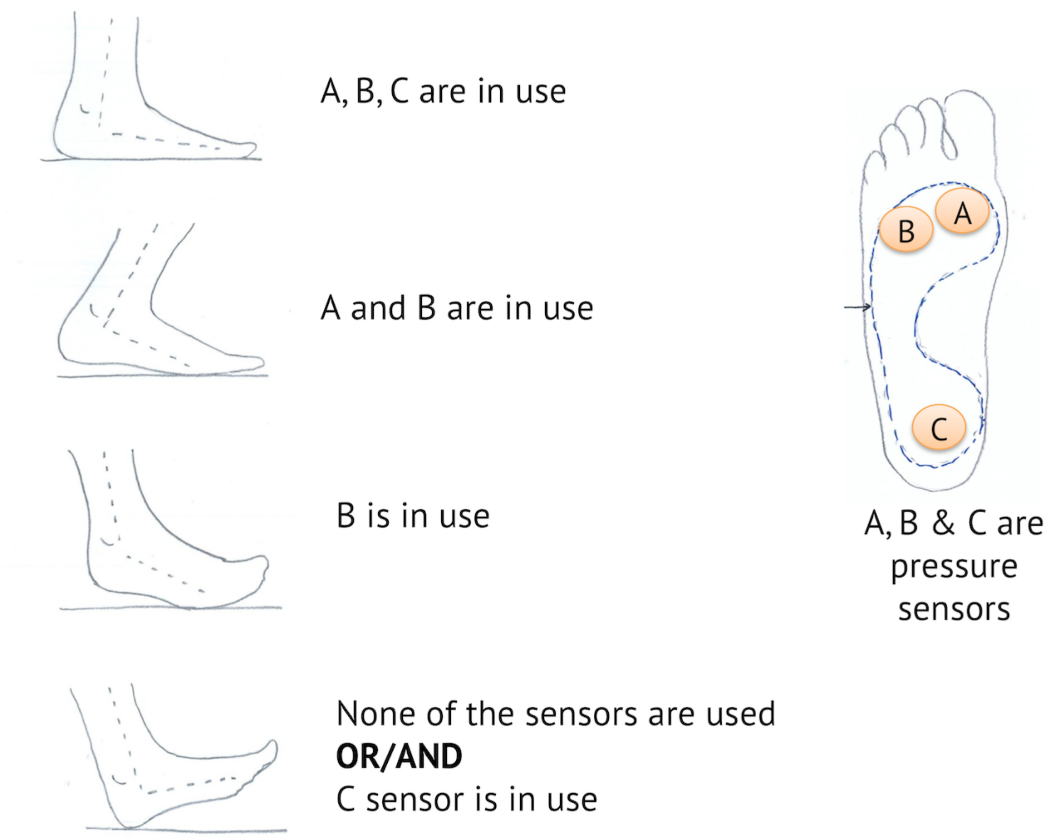


Figure 5-9: The paper-based sketches were developed to explore potential ways of presenting the foot orientation visualisation, when there were issues in making meaningful representations from the flex sensor data.

challenges in generating meaningful data from the flex sensors. Only in the last iteration, the interface was finally developed around these paper sketches when I switched to using the IMU sensor. The IMU sensor generates rich data around xyz coordinates, which I utilised to meet the design goals.

V2: Designing to Support Clinicians in Real-time

The aim was to develop a web-interface that could supplement the information space of clinicians in real-time during video consultations. It was essential that the interface should generate the least distraction for the clinicians, and that the information should be easy to interpret in real-time during video consultations. To fulfill these design goals, I tried to develop intuitive representations and followed metaphorical visualisations. I minimally utilised numbers and graphs, as they require more cognitive efforts for interpretation and are particularly difficult to process in real-time (Galesic and Garcia-Retamero, 2011). Additionally, the web-interface was iteratively refined to get visual consistency and to improve its readability for real-time data visualisation. Figure 5-8a & b shows the earlier iterations of the web-interface, where the major changes happened around the color spectrum and circle size for representing the pressure sensor data.

To support clear verbal communication between the clinicians and patients around the interface, I utilised different colors to represent the variation in movements. This design choice was guided by the suggestion of the collaborating physiotherapist. In the beginning, I utilised seven discrete colors to represent the weight distribution patterns, where each color represented a range of pressure values, and each range was demonstrated through different circle sizes - 7 sizes in total. However, after testing with multidisciplinary experts in the lab, I switched to using a continuous color spectrum to make the order of different colors more intuitive (as shown in Figure 5-8b). Also, to maintain consistency in the visualisation, I reduced the number of circle sizes from 7 to 3 and made the circles static on the web-interface. The visualisation was further refined in the following iterations and the final visualisation includes three concentric circles of different sizes each representing a category (Low, Medium and High); a continuous spectrum of colors from light yellow to dark red; and a number in the range of 0-30. The concentric circles remain static on the web-interface, whereas the color and number change in real-time to represent the category of weight distribution. (Figure 5-8c shows the final visualisation of weight distribution.)

Since the goal was to establish real-time communication, some design decisions were also made around the technical feasibility of updating the visualisation in real-time. For instance, after switching to IMU, I initially explored 3D visualisation of foot movements by using the open source library of the Adafruit IMU sensor. However, I did not go much farther with it because the 3D visualisation was resource-intensive and required a high bandwidth of data transmission for each sock. This further became a challenge when the data was required to be sent to the server (via Bluetooth) to update the web-interface on the clinician end. Finally, I switched to 2D representation and used foot sketches to visualise foot orientation and range of movement. The 2D representation offered a quick and feasible way to update the interface in real-time because sketches are smaller in size (in KBs). Using sketches as opposed to using photographs also improved the readability of the visualisation, as sketches removed the background information (e.g., room structure, skin color, and foot structure) and offered a clear and direct visualisation. Furthermore, it also served a side benefit of making the visualisations neutral to age and gender. (To learn sketching, please refer to the book by Greenberg and colleagues (Greenberg et al., 2011).)

V3: Visualising Patient's Movements from Multiple Perspectives

One important aim while developing the visualisation was to expand the patient's field-of-view in video consultations. To fulfill this, I developed foot sketches from different viewpoints, each presenting key parameters of the lower body movements. For instance, to present the weight distribution over the foot, I utilised sketches of the underside of the foot. This decision was inspired from the existing commercial device called Sensoria socks, which utilise view of the foot sole to present pressure sensor data. Similarly, I utilised sketches of the side view to present the foot orientation data across four directions - lateral, medial, dorsiflexion and plantarflexion. Here, I chose side view over front view because the front view of the patient's feet is already available in a typical video call, and therefore, the side view would provide a different perspective of the patient's feet to the clinicians.

To present foot orientation, I initially created 5 sketches to demonstrate foot movements across each direction - 20 sketches in total. However, the lab testing with experts showed that the small differences in orientations were not evident through sketches. Instead a number called as flex degree, which later became the measure of the range of movement, proved helpful in highlighting the difference. Later, I reduced the number of sketches considering the degree of movements that our foot follows, e.g., higher degree in the front and backward direction (dorsiflexion and plantarflexion), whereas lesser in either side (lateral and medial). And the final visualisation includes a set of 10 sketches: three each for dorsiflexion and plantarflexion and two each for medial and lateral orientations. These sketches update on the web-interface in real-time based on the sensor data. I also wanted to make a note that there could be other orientations such as a combination of lateral and dorsiflexed foot, which I did not consider for the simplicity of the visualisation.

V4: Making the Sock Design Apparent in the Visualisation

While sketching out the possible visualisation schemes, I found that the collaborating physiotherapist appreciated those schemes that explicitly showed the design of the sock. He wanted to have a clear understanding of how the data is captured. For instance, to visualise weight distribution, I presented him with five schemes, as shown in Figure 5-10. These schemes mainly utilised heat maps in two ways: one presenting the heat maps in circular forms only at points where the sensors were located on the socks (Figure 5-10c, d & e); and another having a continuous patch of the heat map on the sole (Figure 5-10a & b). The circular representation with solid colors (Figure 5-10d & e) was inspired by the earlier work on supporting the rehabilitation of the patients using sensor-based tiles (Bongers et al., 2014). The physiotherapist appreciated the circular representation of the heat map because it mimicked the shape and location of the pressure sensors attached to the socks and made the representation more intuitive than a continuous patch. I, therefore, utilised the circular representation to visualise information of the weight distribution.

V5: Integrating the Clinical Practice of the Collaborating Hospital

Some design decisions were taken by considering the clinical practice of the collaborating hospital. At the Royal Children's Hospital, clinicians use two screens during

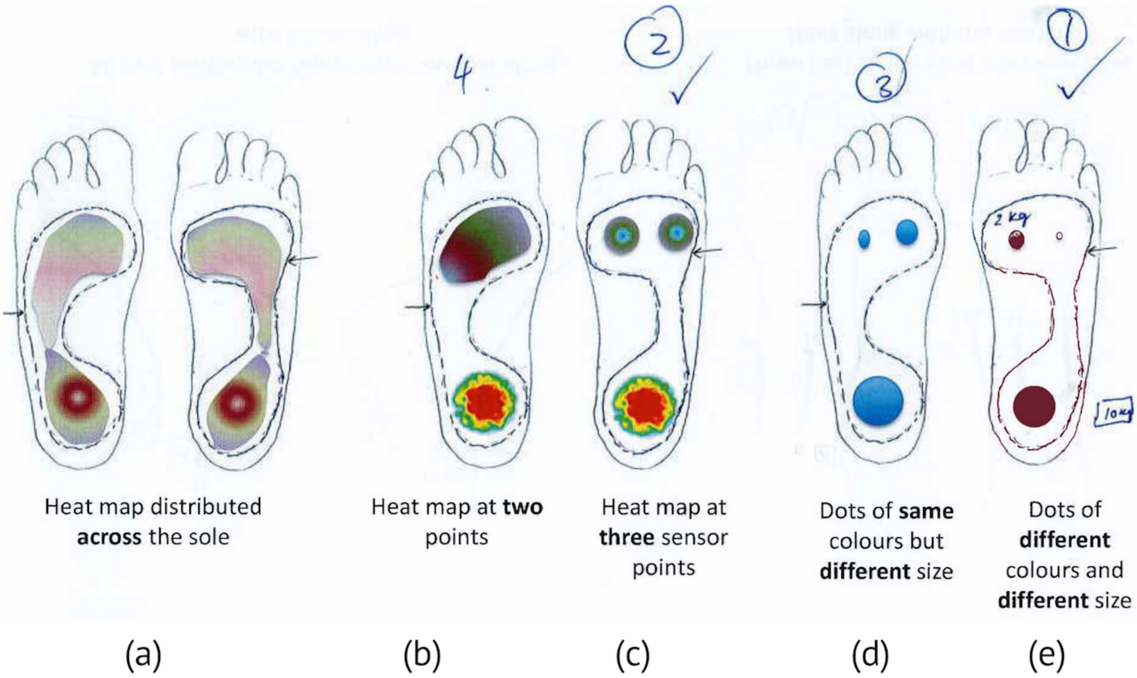


Figure 5-10: The collaborating physiotherapist ranked the potential visualisations for presenting weight distribution data on paper. He suggested using solid colors to present the weight distribution patterns on three dominant locations of the foot (e).

video consultations – one for the video stream, and another to perform other tasks such as to open the patient's medical reports or to check the calendar for scheduling the next consultation. The collaborating physiotherapist suggested presenting the visualisation on a separate screen so that it does not affect the video stream of the patient. Hence, the video stream was not embedded in the developed interface because doing so would have reduced the screen size of the patient's video stream, thereby, influencing the visual assessment made from the video stream. Additionally, integrating the video stream into the web-interface would have also created a concern regarding the privacy of data transmission. The video conferencing tools used at the hospital follow encrypted and secured data communication to ensure the privacy of the patient, which was difficult to achieve with a research prototype. As such, I aimed at creating a web-interface that would require least changes from the ongoing clinical practice at the hospital to make field deployments of the designed prototype feasible in Study 3 (Study 3 is discussed in Chapter 7). This resonates with the suggested practice of field deployments in the health domain (Blandford et al., 2015).

5.5. SoPhy: The Proposed System

The outcome of the multiple iterations of the socks and web-interface was a working prototype that can sense the patient's movements and can present the information to

Figure 5-11: Design of the *SoPhy* socks: The socks have sensors attached to the sole and bridge of the foot to capture lower body movements of the patients.

physiotherapists in real-time during video consultations. I named this system as *SoPhy* (pronounced as Sophie), which stands for ‘Socks for Physiotherapy’. *SoPhy* is a wearable technology that is designed to support lower limb assessment and treatment during video consultation of physiotherapy. *SoPhy* has two parts: (1) a pair of socks for the patients containing three pressure sensors placed at the sole and one Inertial Measurement Unit (IMU) attached on the bridge of the foot (Figure 5-11); (2) and a web-interface that presents information related to weight distribution, foot orientation and range of movements to physiotherapists in real-time (Figure 5-12).

The system works as follows: Patients wear the *SoPhy* socks before starting the video consultation with their physiotherapist. During the video consultation, the socks capture data about foot movements when the patient performs the prescribed lower body exercises (e.g., squats and tip toes). This data is then sent to the web interface, where the physiotherapist can see this information in real-time. A mobile app supports the communication between the socks and the web interface, via a Bluetooth shield[18] attached to the socks (on the microcontroller). Figure 5-13 presents the system architecture of *SoPhy*, and Figure 5-14 shows the circuit diagram of *SoPhy*.

[18] Sparkfun Bluetooth Silver Mate. https://www.sparkfun.com/products/12576

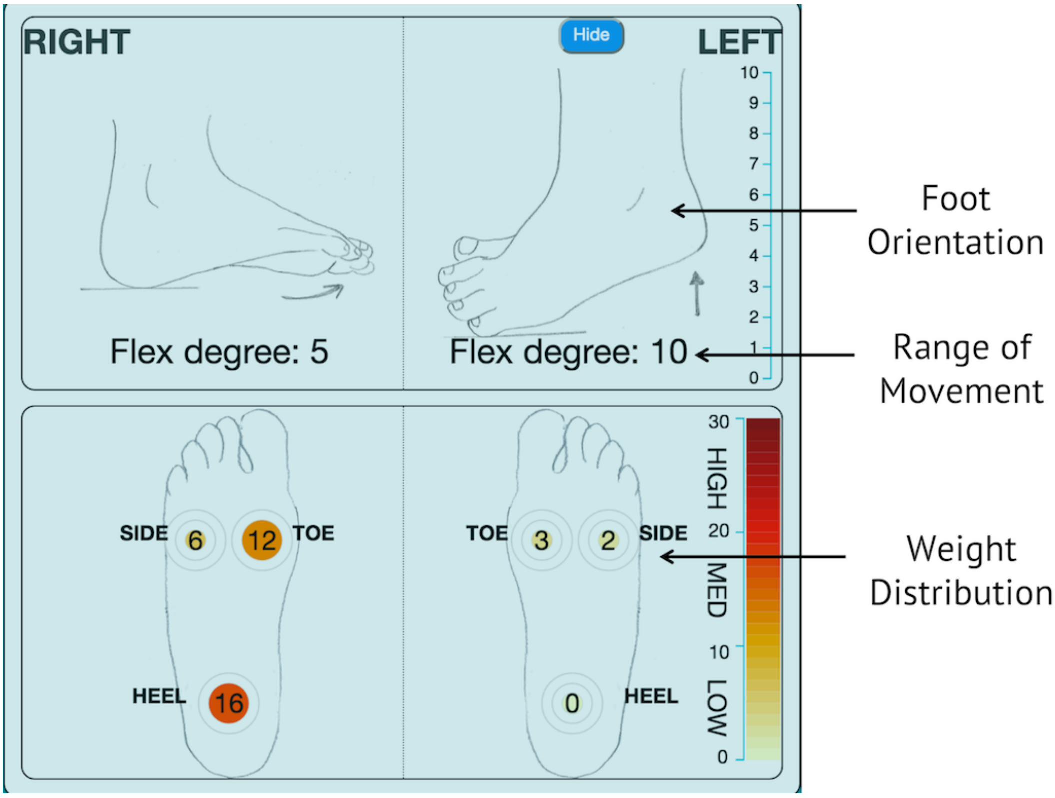


Figure 5-12: Design of the *SoPhy* web-interface: The web-interface presents visualisation related to foot orientation, range of foot movement and weight distribution.

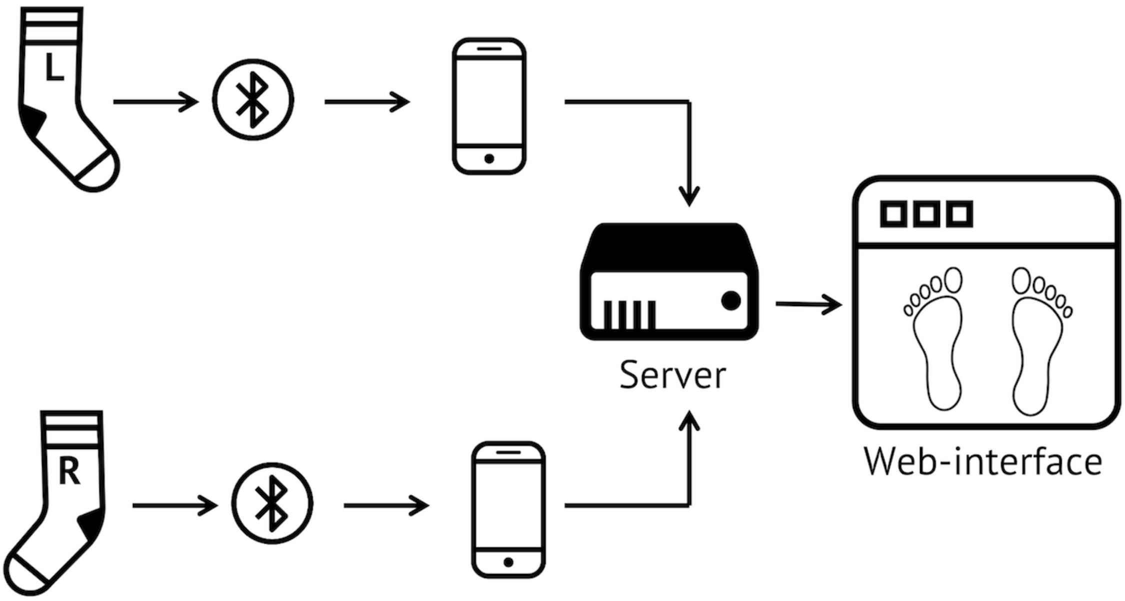


Figure 5-13: *SoPhy* architecture: Each sock communicates the sensor data to a mobile app via Bluetooth. The mobile app then communicates the data to the server. Finally, *SoPhy* web-interface fetches the data from the server after every few seconds.

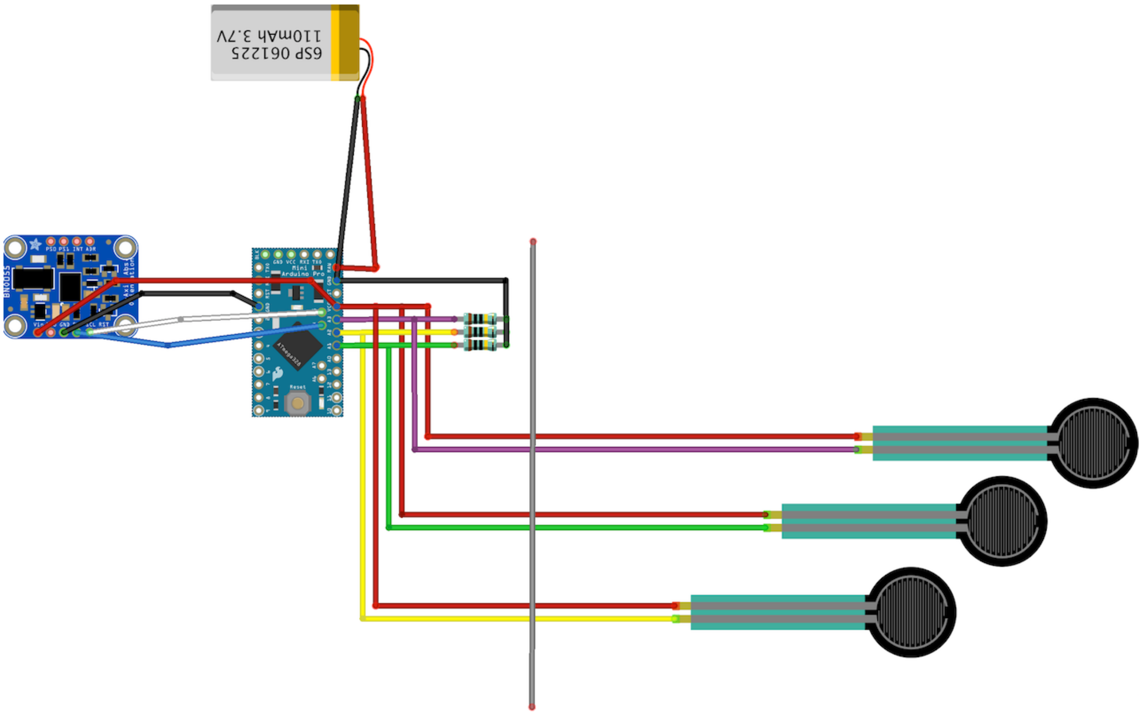


Figure 5-14: The circuit diagram of *SoPhy* illustrating the connections of different sensors with the Arduino Pro-mini board.

SoPhy captures and presents data related to weight distribution, foot orientation, and range of movement in the following way:

Weight Distribution

Weight distribution describes the amount of weight a person is bearing at different points on the sole of the foot e.g., on toes, balls and heel. A healthy person bears equal weight on each foot, however, the pattern changes in case of a lower limb injury. For example, if the big toe of a foot is injured, the person may bear more weight on the outside of the foot.

SoPhy captures the pattern of weight distribution across the balls and heel of the foot through the pressure sensors sewed on the socks. Corresponding to each sensor, the interface presents a circle on a sketch of the underside of the foot (refer Figure 5-12). These circles are representative of the locations of the sensors attached to the socks. For each sensor, weight distribution is presented using both colors and numbers. The color spectrum denotes the measure of the weight on each point, and the number shows the pressure values on a scale of 0-30. With the increase in the pressure sensor value, the color gradually changes from light yellow to dark red, and a number between 0-30 appears inside the circle to represent the sensor value. Each sensor point has three concentric circles with each circle representing a distinct range of pressure values – Low (0-9), Medium (10-19) and High (20-30).

Foot Orientation

Foot orientation refers to the alignment of the foot in four directions, as described in the medical literature (Grand, 1967; Sarrafian and Kelikian, 2016). These orientations are described as dorsiflexion, plantarflexion, medial orientation, and lateral orientation.

- *Dorsiflexion* happens when the foot or toes are flexed (or bent) in the upward direction towards the head. In human anatomy, the top of the foot is called the dorsum of the foot, hence any movement in the upper surface is referred to as dorsiflexion.
- *Plantarflexion* occurs when the foot is pointing downwards away from the leg, or the toes are curled down towards the sole. In human anatomy, the sole of the foot is called the plantar surface, and the foot movement in the direction of the plantar surface is referred to as plantarflexion.
- *Medial orientation* happens when the foot moves towards the median (central) plane, i.e., the person lifts the outside of the foot up in the air.
- *Lateral orientation* occurs when the foot moves away from the median plane, i.e., the person lifts the inside of the foot up in the air.

Foot orientation is captured by an IMU sensor mounted on the socks near the bridge of the foot. On the web-interface, foot orientation is presented using multiple pencil-based sketches: three each for dorsiflexion and plantarflexion, and two each for medial and lateral orientation (refer Figure 5-12). These sketches change in real-time based on the captured data.

Range of Movement

Range of movement refers to the magnitude of the foot orientation across four directions described above. The range is defined on a scale of 1 to 10 (refer Figure 5-12) and is calculated from the IMU data. On the web-interface, this value is represented as a ‘Flex degree’ underneath each foot sketch.

5.6. Discussion

The design phase aimed at designing an interactive system that can help the physiotherapists in assessing patients with lower limb issues during video consultations. The development started by listing out the essential bodily cues that the physiotherapists need to assess the patient’s lower limb functioning, which was followed by a review of the available commercial devices for rehabilitation (e.g., sensing socks and shoes) that could potentially provide information about the selected bodily cues. From the review, I identified that none of the existing devices were specifically designed to capture the selected bodily cues. Also, some devices like Sensoria socks, which could potentially be appropriated to achieve the design goals did not offer open API at the time of the study. However, the design of the existing devices provided sufficient inspiration to design a research prototype. Finally, I chose to design sensing socks because socks being a wearable will move with the patient, and therefore, will accurately capture both the static and dynamic movements.

Following iterative prototyping, I designed a wearable technology *SoPhy* that captures and presents three key aspects of the lower limb movements – weight distribution, foot orientation and range of movement. In response to my sub-questions Q1 and Q2, *SoPhy* has two components – a pair of socks and a web-interface. At the patient side, *SoPhy* socks sense the patient's movements through different sensors embedded on the sole and bridge of the foot (Q1). While at the physiotherapist side, the captured data is presented in real-time on the web-interface (Q2). The design decisions to iterate the design of the socks and web-interface were informed by the needs of the patients and physiotherapists. Table 5-2 summarizes the design decisions taken during the design phase.

With regards to the sub-question Q1, different factors guided the design of the socks. The biggest factor was to design a pair of socks that are comfortable for the patients to wear (S1). Consequently, normal socks were chosen over the 5-toed socks, as normal socks would be more comfortable for patients who have swollen foot. Also, several design decisions were made that conflicted with the procedures and principles of the wearable technology, e.g., Arduino ProMini and conductive wires were adopted instead of using the LilyPad and conductive threads because these electronic components provided a compact and robust design of the SoPhy socks. Secondly, the design

SoPhy Iterations	Design decisions across different iterations
Iterations of the socks	S1: Designing for the patient's comfort S2: Designing to accommodate different foot structure S3: Embracing human anatomy into the design
Iterations of the web-interface	V1: Developing visualisation in parallel with the socks V2: Designing to support clinicians in real-time V3: Visualising patient's movements from multiple perspectives V4: Making the sock design apparent in the visualisation V5: Integrating the clinical practice of the collaborating hospital

Table 5-2: Summary of the design decisions that guided the development of the *SoPhy* socks and web-interface.

required socks to be accommodative of different foot structures (e.g. long toes and wide foot) so as to avoid dislocation of the sensors (S2). As a result, different insertables like a water bottle and a foot model, and design strategies such as using multiple layers of cloth were used to develop stretchable socks. And finally, knowledge of the human anatomy guided some decisions around the selection and positioning of the sensors (S3). For example, pressure sensors were placed at three locations on the sole, where the healthy people bear maximum weight. While on the other hand, flex sensors were dropped because our foot has limited movements around the ankle joint and the sensors were not sensitive to capture such subtle movements.

Similarly, the interface was iteratively developed in consideration with the clinical practice of the physiotherapists, which answers the second sub-question Q2. Firstly, the web-interface was developed in parallel with the socks (V1), which helped me to identify the potential utility of the different sensors in fulfilling the design goals. The biggest challenge of working with the sensors is to make sense of the generated data. Therefore, while selecting sensors for the socks, I kept myself inquiring about how to make sense of the captured data, and what kind of visualisations can be developed through the captured data. As a result, I discarded using the flex sensors and accelerometers, as the generated data was difficult to process to develop informative visualisations. Secondly, the visualisations were developed with an aim to have real-time usage by the physiotherapists (V2). Consequently, the visualisations were kept simple so that the presented information could supplement the diagnostic thinking of the clinicians in real-time and that they do not require much cognitive efforts in interpreting the information. I, therefore, utilised the color spectrum and foot sketches to present the captured data instead of using the graphs. Additionally, the goal of presenting data in real-time also influenced the form of visualisation. In this regard, I did not utilise 3D visualisations because such visualisations need high bandwidth for data communication. Instead, 2D visualisations through foot sketches were used because it supported real-time update of the captured data on the web-interface.

Moreover, some design decisions were taken in order to present the patient’s movements from different perspectives, so that the physiotherapists have a much better understanding of the patient’s movements during video consultations (V3). As a result, foot sketches were developed from different viewpoints for different visualisations, e.g., the weight distribution is visualised through sketches showing feet from the underneath, and range of movement is presented through sketches showing feet from the side. Another aim was to design such visualisations, which could make the design of socks transparent to the physiotherapists (V4). In this regard, different visualisation strategies were utilised to make the shape and positioning of the sensors explicit on the web-interface. For example, the weight distribution data is visualised using three circles presented at the same location where the pressure sensors are attached to the socks.

Such a design of the visualisation made the working of the *SoPhy* socks explicit to the collaborating physiotherapist.

And finally, some design decisions were inspired by the clinical practice followed at the collaborating hospital (V5). In this regard, *SoPhy* visualisation is presented on a separate screen instead of presenting it on the video stream. Presenting the visualisation on a different screen helped in retaining the size of the patient's video call. As such, the information presented on the web-interface is designed to complement the visual assessment of the physiotherapists through the video stream.

5.7. Summary of Contributions

This chapter makes the following contributions:

1. Firstly, by developing a sensor-based system, *SoPhy,* I investigated a new direction for video consultation systems. To the best of my understanding, this is the first design exploration in the context of physiotherapy related video consultations. In this regard, *SoPhy* extends the existing HCI literature of video consultations (Fitzpatrick and Ellingsen, 2013; Mentis et al., 2016a; Stevenson, 2010) and highlights opportunities of using sensing technologies to make video consultations more effective for assessment.

2. Secondly, through *SoPhy*, I operationalised three key aspects of the lower body movements that are crucial for the physiotherapists to assess patients with lower limb issues. This is a novel contribution as the existing systems for lower limb rehabilitation like Sensoria socks and Nintendo Wii balance board, do not provide information related to these three key parameters. Also, by investigating the design space of the lower limb movements particularly feet, this chapter also extends the existing literature on the technologies for rehabilitation that are either focused on the computer vision methods (O'Hara et al., 2016; Tang et al., 2015), or have explored wearable technologies for other body parts such as knees (Ananthanarayan et al., 2013; Ayoade and Baillie, 2014; Lam et al., 2016).

3. Finally, I provide a detailed account of how the design phase progressed and how different challenges were encountered during the iterative design of *SoPhy*. By illustrating the design process across eight design decisions (as listed in Table 5-2), the chapter provides practical guidelines on how to design a wearable technology for the context of video consultations. Also, by providing the narration of how the list of shortlisted bodily cues for lower limb movements was refined across different iterations, the chapter also illustrates the technical

challenges of capturing the bodily movements accurately, which designers need to consider while designing sensor-based systems.

5.8. Conclusion

This chapter presented the design of a novel wearable system, *SoPhy*. *SoPhy* aims to support physiotherapists in assessing patients with lower limb issues during video consultations by providing three key bodily information – weight distribution, foot orientation and range of movement. I embraced the human-centred design approach to iteratively design *SoPhy*, where I collaborated with a senior physiotherapist from Royal Children's Hospital.

SoPhy was designed by considering the needs of the potential users. However, the limited access to the physiotherapists and patients raised the question whether the system would work in the real-world hospital settings and whether it requires further iterations to satisfy the user needs. Therefore, the next step was to evaluate whether and how *SoPhy* helps the physiotherapists during video consultations. However, instead of directly deploying *SoPhy* at the hospital setting, I first conducted controlled lab experiments (Study 2) to ensure that *SoPhy* has benefits for the physiotherapists and that it would not create any issues for the patients already under pain. The next chapter describes the laboratory evaluation of *SoPhy,* where I ran a comparative study of video consultations with and without *SoPhy*, to understand its utility. Later, I field deployed *SoPhy* in real video consultations organised at the hospital to evaluate its potential in enhancing the overall efficacy of physiotherapy related video consultations – which formulated the final study of this thesis discussed in Chapter 7.

Chapter 6
Study 2: Laboratory Evaluation of SoPhy

Overview: This chapter presents the second study of the thesis with details on the study procedure, study findings, and discussion of the findings to underline potential applications of *SoPhy* in the practice of physiotherapists.

Key Publications: The content of this chapter is based on the following publication (listed in Appendix E.3):
Aggarwal, D., Zhang, W., Hoang, T., Ploderer, B., Vetere, F., Bradford, M., 2017. SoPhy: A Wearable Technology for Lower Limb Assessment in Video Consultations of Physiotherapy. In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems, CHI '17. ACM, New York, NY, USA, pp. 3916–3928.

Public Presentations: Findings of this study were presented at the following academic venues:
ACM CHI 2017, Denver, USA
5th Annual CIS Doctoral Colloquium, University of Melbourne, 2017

6.1. Introduction

In the previous chapter, I presented the design of a wearable technology *SoPhy* that aims to support physiotherapists in assessing lower limb movements during video consultations. *SoPhy* consists of a pair of socks with embedded sensors for patients to wear; and a web interface that displays information about the range of weight distribution, foot movement, and foot orientation for physiotherapists in real-time.

In this chapter, I will discuss the laboratory evaluation of *SoPhy* in response to the second research question, which is to understand the diagnostic efficacy of *SoPhy* in helping physiotherapists to assess lower limb movements. The study was conducted by simulating the setting of video consultations with postgraduate physiotherapy students in the lab. The structure of the chapter is as follows: Section 6.2 describes the study aims. Section 6.3 describes the overall study design, with details of the tasks performed by the participants, and the methods for data collection and analysis. Section 6.4 illustrates the study findings in terms of the benefits and issues experienced by participants with *SoPhy*. Section 6.5 provides a discussion of the findings and underlines potential applications of *SoPhy* in the clinical practice of physiotherapists. The section also lists three design considerations to integrate novel video consultation systems like *SoPhy* as part of the clinical practice of physiotherapy. Section 6.6 provides a summary of the contributions related to this study, and Section 6.7 concludes the chapter.

6.2. Study Aims

This study explores the second research question of the thesis:

RQ2:	How does *SoPhy* influence the efficacy of physiotherapists in assessing lower limb movements in (simulated) video consultations?

As presented in the last chapter, *SoPhy* offers information related to three parameters of lower limb movements - weight distribution, foot orientation and range of movement. Since this study was the first evaluation of *SoPhy*, the aims of this study were twofold: firstly to understand how *SoPhy* helps physiotherapists in assessing patients, and secondly to identify any issues in its design. In this regard, I further broke down RQ2 to the following three sub-questions:

Q1. How does *SoPhy* influence the diagnostic efficacy of physiotherapists in assessing patients?

Q2. What information do the physiotherapists draw from *SoPhy* to assess the patients?

Q3. How can we improve the technical efficacy of *SoPhy*?

To measure the diagnostic and technical efficacy of *SoPhy*, as described in Chapter 2 (Section 2.2.5). Taking a stepwise approach to evaluating *SoPhy*, I structured this study specifically around assessment and did not focus on the treatment. The study was conducted in collaboration with a senior physiotherapist (pseudonym: Phil) at the Royal Children's Hospital in Melbourne, Australia. Approval for conducting this study was received from the university ethics committee, HREC #1646826. (Appendix C.1 shows the plain language description provided to the study participants).

6.3. Evaluating SoPhy

Following experimental research methodology (Cook and Campbell, 1979; Gergle and Tan, 2014), I conducted this study by simulating video consultations of physiotherapy in a laboratory setting. I intended to mimic the structure of video consultations as closely as possible in the lab in order to achieve greater external validity of the study findings. To this end, I simulated video consultations across two rooms in the lab and recruited postgraduate physiotherapy students as study participants. These participants role-played as patients and physiotherapists in the simulated video sessions. Skype was used to organise video conferencing, as it is one of the standard tools at the collaborating hospital. I created patient profiles to simulate real-life patients in these consultations and to convincingly evaluate the assessment process of physiotherapists. The study was designed in consultation with the collaborating physiotherapist (pseudonym: Phil) from the previous studies. I will describe his role in the respective sections. Below I discuss the study design for evaluating *SoPhy* in the laboratory.

6.3.1. Participants

I recruited participants to play two types of role: 1) the physiotherapist and 2) the patient. I chose to recruit postgraduate physiotherapy students as potential participants of the study because they closely represented the target users of *SoPhy* in a real-world setting. Participants were recruited from the university's mailing list of postgraduate physiotherapy students through a professor at the physiotherapy department. The email invitation included a brief of the study with a link to a webpage containing more information about the study. (Appendix C.2 presents the email advertisement and snapshots of the webpage describing the study tasks for both roles.)

For the physiotherapist role, I recruited 10 students (3 male, age range: 23-28 years) from the second and third (final) year of the postgraduate physiotherapy degree from the university campus (7 from the third year and 3 from the second year). For this role, participants were expected to have completed formal training on standard patient assessment and treatment for patients undergoing different health issues. As part of the degree program, participants had prior experience in role-playing different patient profiles to learn assessment and treatment. Additionally, by the end of the second and final year, these students are respectively required to complete 19 weeks and 37 weeks of clinical practice at hospitals, where they assist physiotherapists in treating patients. I utilized their skills to evaluate the utility of *SoPhy* by asking them to play the role of physiotherapists in the evaluation. Participants had no prior experience with video consultation or sensing technology for rehabilitation (e.g., Wii-fit board and Sensoria socks). Participants received a $20 gift voucher as a token of appreciation.

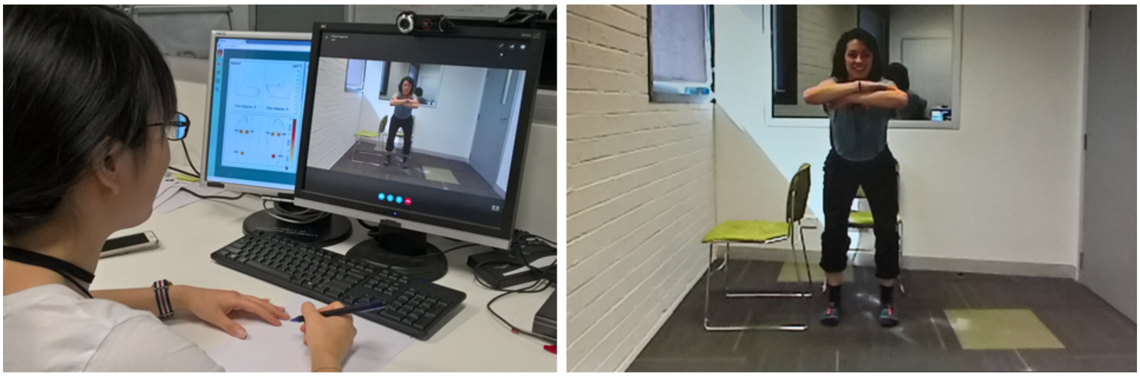


Figure 6-1: Study set up: (a) Participants used the *SoPhy* interface during the study in sessions *with SoPhy*. (b) The actor performed different exercises like squats by wearing the *SoPhy* socks.

For the patient role, I hired a final year physiotherapy student (female, 28 years old) to play the role of the patient in the entire study. This decision as modeled after the earlier study (Hoang et al., 2016), as having one actor helped in getting consistency in the study setup and therefore, minimised the control variables. I refer to the patient as an actor to avoid any confusion with participants. I appointed her as the candidate because of her prior experience in assisting physiotherapy sessions as well as her consistency in performing the exercises for different patient profiles. The actor was paid $25 per session for her participation in the study.

6.3.2. Study Design

The aim of this study was to understand how *SoPhy* helps physiotherapists in formulating their assessment and what challenges do they face in using *SoPhy*, when video consultations are simulated in a laboratory setting. The evaluation involved video consultations *with SoPhy* as the test condition and standard video consultations *without SoPhy* as the baseline condition. The actor and participants were in two different rooms to simulate a real-time video consultation setting in the lab (refer to Figure 6-1). In both conditions, communication was conducted through a Skype video call. For the *with SoPhy* condition, participants were presented with the visualisation interface of *SoPhy* in addition to the Skype screen. The baseline condition was included in consideration of the situation that study participants might not be aware of video consultations, as it is comparatively a new clinical practice. The baseline condition proved helpful, as the study participants had no prior experience with video consultations. To this end, sessions with standard video consultations provided them with background knowledge on how a standard video consultation happens, and thereby, they could compare the merits of using *SoPhy* in video consultations.

Moreover, to evaluate the utility of *SoPhy* in different health conditions, I also included two pain conditions – extreme pain and low pain. These pain conditions were introduced because the patient's movements vary considerably based on their health condition. And since *SoPhy* is designed to capture the movements of patients, it is crucial to investigate how different health conditions of the patient influence the potential use of *SoPhy* for physiotherapists. An important point to note here is that health conditions involve several parameters, but I limited it to only pain conditions, as pain plays a crucial role in defining patient's movements. For example, a person in low pain can perform the exercises more fluidly, whereas the person in extreme pain may be reluctant to perform any movements. Hence, these two pain conditions helped me to investigate the utility of *SoPhy* across two extremes. Also, movements for these extreme conditions were easier to simulate in a lab setting.

To this end, the laboratory evaluation consisted of four experimental conditions – (1) video consultations *with SoPhy* for low pain profile, (2) video consultations *with SoPhy* for extreme pain profile, (3) standard video consultations *without SoPhy* for low pain profile, and (4) standard video consultations *without SoPhy* for extreme pain profile. Table 6-1 lists the four experimental conditions of the study. The order of these conditions was randomised to balance out the possible learning effects.

Tasks Performed by the Participants

Each participant was asked to conduct four consultations corresponding to each experimental condition - two each with and without *SoPhy* (as listed in Table 6-1). I randomized the order of these sessions to avoid any learning effect. To help the actor in mimicking movements for the different experimental condition, I created different patient profiles (discussed later in this section). Figure 6-2 provides a summary of the tasks performed by the participants. In all four sessions, participants requested the patient to perform six exercises (as shown in Figure 6-3), and filled out the Patient Assessment Form (discussed later in Data Collection Section 6.3.3). After four sessions, I interviewed the participants to understand their overall experience with *SoPhy*.

	Low Pain Profile	Extreme Pain Profile
Video consultation *with SoPhy*	Condition 1	Condition 2
Video consultation *without SoPhy*	Condition 3	Condition 4

Table 6-1: Four experimental conditions of the study to evaluate *SoPhy*.

Figure 6-2: Summary of the activities performed by the actor and participants for a study session having the order *without SoPhy, with SoPhy, with SoPhy,* and *without SoPhy*. Each participant organised four video sessions and the actor performed different exercises as per the given patient profile. (Student researcher in the image refers to me.)

Each participant took around two hours to finish the study. As such, participation in the study required multiple tasks from the participants. Appendix C.3 presents the script that I used at the beginning of the study to introduce participants to the study tasks.

Tasks Performed by the Actor

The actor was instructed to perform the following six exercises based on the patient profile: (1) dorsiflexion, (2) plantarflexion, (3) double leg squats, (4) single leg heel raises, (5) double leg heel raises and (6) walking. Dorsiflexion and plantarflexion were performed while seated, and rest exercises were performed in standing. Figure 6-3 shows a snapshot of these exercises. I selected these exercises after consulting with the collaborating physiotherapist as these exercises were representative of their clinical practice, and also, they were are not physically demanding for repeated performance

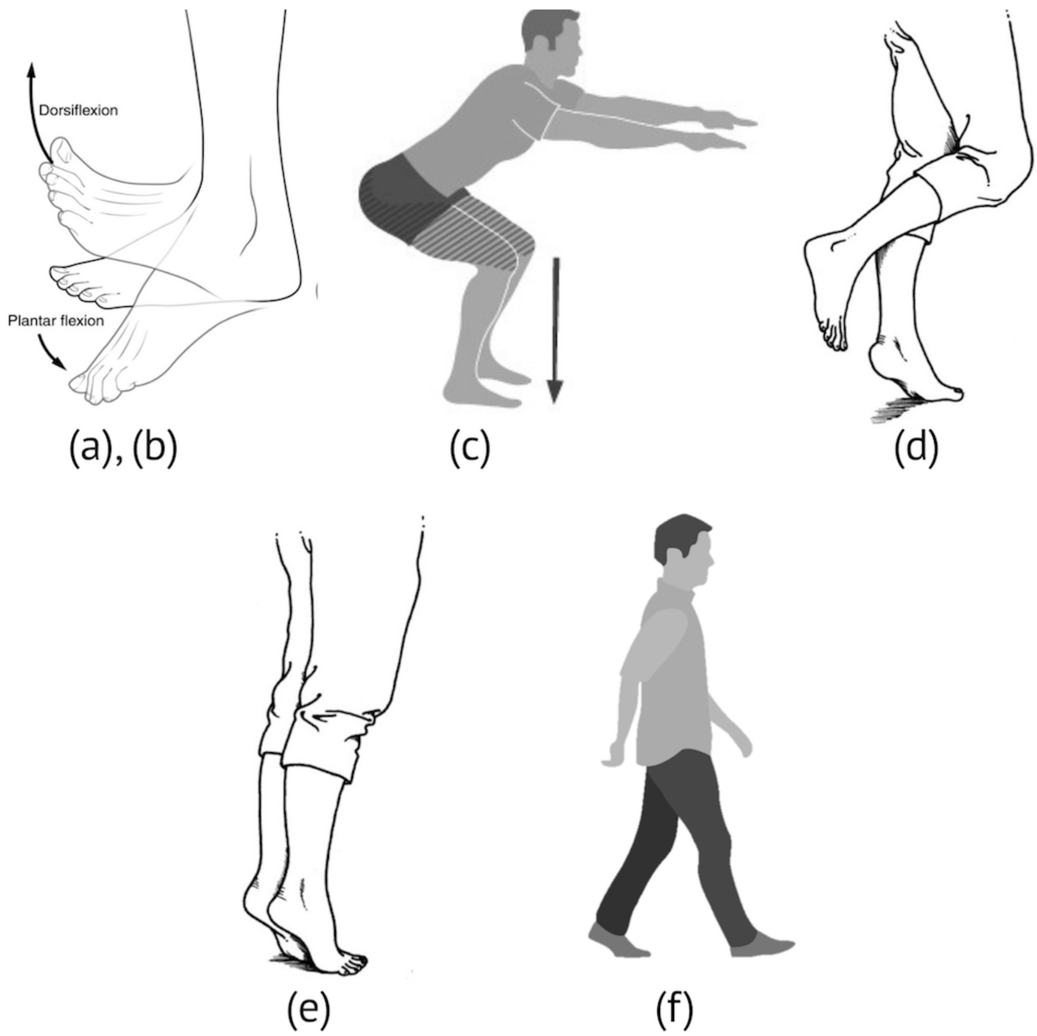


Figure 6-3: The actor performed the following exercises based on the patient profiles: (a) dorsiflexion, (b) plantarflexion, (c) squats and (d) single leg heel raises, (e) double leg heel raises, and (f) walking.

by the actor. The actor was instructed to perform each exercise for the number of repetitions specified in the patient profile unless requested otherwise by the participants. Figure 6-2 lists the tasks performed by the actor during the study. (Appendix C.4 presents the script given to the actor for consistent performance.)

Independent Variables

Independent variables of the study were the *consultation technology* (*with SoPhy* and *without SoPhy*) and *pain conditions* (*extreme pain* and *low pain*). Based on these independent variables, I designed a 2x2 within-subject study with four conditions: *with SoPhy-extreme pain, with SoPhy-low pain, without SoPhy-extreme pain,* and *without SoPhy-low pain*. Every participant, therefore, organised four sessions corresponding to these study conditions.

Dependent Variables

Since the aim of this study was to evaluate how *SoPhy* contribute to the diagnostic efficacy of physiotherapists, the dependent variables of the study included the three parameters supported by *SoPhy* and the measure of diagnostic efficacy. I utilised the confidence in assessment and number of repetitions required to assess exercises as key factors to measure the effect of using *SoPhy* on diagnostic efficacy of physiotherapists in video consultations. To this end, the dependent variables of the study were: *weight distribution, foot orientation, range of movement, confidence* and *exercise repetitions*. Information related to the weight distribution, foot orientation, range of movement, and confidence was filled in by the participants in the *Patient Assessment Form*, whereas the number of exercise repetitions was calculated from the video recordings.

Patient Profiles

Since each participant conducted four consultations, I created four patient profiles so that participants find every patient as unique and there is no learning effect. The patient profiles were created in consultation with the collaborating physiotherapist around two pain levels: extreme pain and low pain. I limited the profiles to extreme and low pain to study the utility of *SoPhy* in assessing two extreme forms of movements. Besides, these extreme opposites also made it easier for the actor to consistently perform the respective roles. Table 6-2 illustrates the names for each profile, where Sam and Veena had the similar injury in the left foot and were in extreme pain, whereas Susan and Vicky had the similar injury in the right foot and were in low pain. The order in which each participant was exposed to the patient profiles was randomized. (Appendix C.4 shows how these patient profiles were presented to the actor.)

Pain Profiles	*with SoPhy*	*without SoPhy*
Extreme pain	Sam	Veena
History Taking	Susan	Vicky

Table 6-2: Four patient profiles were created around the pain conditions (extreme and low pain) and consultation technology conditions (with and without *SoPhy*).

Participants were provided with the background details of each patient that described the cause of injury and how the patient condition had changed over the period; whereas the details of the pain and other socio-emotional factors that define movements were only provided to the actor. Table 6-3 shows details of the two patient profiles for extreme pain. For these profiles, I presented the following information to the actor: asymmetric walking with less weight on heel of the left foot, fearful of walking and touching, constant pain, swelling in ankle and outside of the left foot, extreme pain today with pain level 6 (on a scale of 0 to 6). Also to define the patient's emotional condition, the following details were provided: living with working parents, skipping school, isolated from her friend circle and avoiding going to social events.

Sam is a 16-year-old girl who works as a helping hand in a restaurant. Last year, she twisted her left foot during a busy day at the restaurant. After the incident, Sam feels pain around her ankle. The pain is not constant, but on days when she has it, it gets unbearable. She has consulted many clinicians so far, but the pain does not seem to go away. Veena is a 15-year-old high school girl who was very active in sports until 2 years back when she twisted her left ankle. She has been on pain medication for 4 months and has consulted psychiatrist and surgeon. She has recently started physiotherapy to get rid of her pain. She is diagnosed with chronic pain in left foot ankle.

Table 6-3: Details of the two patient profiles for extreme pain condition.

Similarly, Table 6-4 shows details of the low pain patient profiles. To guide the actor in doing the exercises, I presented her with the following information about the physical condition of the patient: walking with the right foot tilted inward, feeling sore in the outer part of the right foot, pain incidences after doing certain activities and feeling energetic today with pain level of 1 (on a scale of 0 to 6). Parameters describing the emotional state of the patient included: living with parents, becoming regular in school, enjoying meeting friends and other social gatherings.

Susan is an 11-year-old girl who loves biking. Two years back, she met with an accident during a marathon and fractured her toes of right foot. She has gone through severe pain in her right toe, which made her immobile for a while. Through the foot based exercises that she has been practicing, she has recovered 90% of her foot movements. She does not have constant pain now, but she is still struggling to bike for longer than 10 minutes.

Vicky is a 13-year-old girl who loves ballet and is a champion in karate. Three years back, she met with a road accident and fractured her big toe of right foot. After the accident, she lost movements in her right foot. Through the foot based exercises that she been practicing, she has recovered 90% of her foot movements. She does not have constant pain now and has resumed her ballet classes once a week. But she still finds difficulty in focusing on the karate.

Table 6-4: Details of the two patient profiles for low pain condition.

For all patient profiles, video sessions were described as a follow-up of the face-to-face consultations, where all patients are already following on the six exercises from the last consultation along with the number of repetitions - five for extreme pain and ten for low pain. Therefore, participants were not required to explain these exercises to the patient in these sessions.

6.3.3. Pilot Sessions

I conducted three pilot sessions to test out the study setup before commencing the study. These sessions were conducted with the actor and my colleagues and ran in the similar way as if they were the real study sessions. In the first and third sessions, the actor performed the exercises according to the patient profiles, and my colleagues role-played as a physiotherapist and filled out the Patient Assessment Form. However, in the second session, the actor acted as the physiotherapist and my colleague acted as the patient. These two mappings helped me in getting feedback from both the physiotherapist and potential participant perspectives. (Appendix C.5 shows the study checklist that I developed at the end of these pilot sessions to list out all the tasks to be done at different times during the study.) In these pilot sessions, I tested a variety of study parameters, e.g., the placement of participants, the orientation of screens, and the arrangement of recording devices. Additionally, I also practiced how to introduce the study to the participants before beginning the session, and how to conduct interviews. The key highlights of the pilot sessions were the following:

Firstly, I checked the arrangement of screens and webcams in both rooms. The aim was to avoid any readjustments of screens or webcams during the study, and therefore, to

Figure 6-4: The arrangement of the participant's room after the pilot sessions - the two screens were placed with a little overlap to provide better readability, and the video camera was arranged behind the participant to capture interactions with two screens.

figure out the proper orientations beforehand. For the participant's room, I found that the two screens – one used for the video call and another for the *SoPhy* web-interface, should slightly overlap with each other. This arrangement allowed participants to simultaneously refer to the visualisation while seeing the patient's movements over video. Also, borrowing from the set up at the hospital in study 1, the webcam was adjusted to capture the upper torso of the participants. Figure 6-4 shows the final setup of the participant room.

Similarly, for the patient room, I figured out that the webcam should be positioned to capture the full body of the actor. The actor was given sufficient space to move around for different exercises, specifically to show the walking pattern. Also, to create realistic movements for the patients, I placed two chairs nearby the actor for her to take support when roleplaying extreme pain patient profiles (Refer Figure 6-5). This arrangement is inspired by my observations of consultations in Study 1, where patients used chairs to take support whenever needed. Having this arrangement helped me in running the sessions smoothly, without the need for any rearrangements and interruptions.

Finally, I verified the Patient Assessment Form to check if the framing of the questions was appropriate and if the form provides sufficient details of the patient profiles for the participants to follow. To this end, I discussed the patient profiles and the Patient Assessment Form with the actor, to verify if the terminologies matched with their clinical

Figure 6-5: The arrangement of the actor's room after the pilot sessions – the webcam was arranged to capture the full body of the actor. Also, the actor was provided with three chairs to take support during exercises.

practice. Based on her feedback, I revised the labels of the scale for different parameters to communicate clear meaning. For example, I changed the labels for a range of movement from "none – moderate – extreme" to "none – partial – complete". Moreover, I removed additional information related to the number of face-to-face sessions that the physiotherapist and patient had prior to the session, as it occurred to be unnecessary. And finally, these sessions also trained the actor to consistently perform the exercises based on different patient profiles, which was essential to reduce errors in quantitative data.

6.3.4. Data Collection

To understand how *SoPhy* influenced the efficacy of physiotherapists in assessing lower limb movements during video consultations, I utilised the efficacy model of clinical systems as explained in Chapter 2 (Section 2.2.5). Since the focus of this study is only on the assessment, I utilised only three aspects of the model corresponding to the Examination phase *diagnostic accuracy efficacy, diagnostic thinking efficacy* and

#	Aspects of clinical efficacy	Parameters corresponding to each aspect (relevant to this study)
1	Technical efficacy	a. Visualisation related to weight distribution, foot orientation and range of movement b. Wearability, visibility and design of the socks
2	Diagnostic accuracy efficacy	a. Instances of correction in the assessment
3	Diagnostic thinking efficacy	a. Understanding of the patient's health issue b. Influence on confidence in assessing the patient c. Ability to assess different types of exercises

Table 6-5: Data collection was guided by three factors of the efficacy model – technical efficacy, diagnostic accuracy efficacy, and diagnostic thinking efficacy.

technical efficacy to evaluate *SoPhy* (refer Table 2-1 in Chapter 2). Table 6-5 describes these three factors and their corresponding parameters that guided the data collection in the study. These factors include several parameters that helped me to get a rich understanding of whether and how *SoPhy* helped physiotherapists in assessing patients during video consultations. The parameters of technical efficacy helped me to evaluate if the bodily information related to lower limb movements provided by *SoPhy* is sufficient for physiotherapists, and if not what might be the issues. To this end, the technical efficacy of the *SoPhy* visualisation was investigated through interviews and observations.

Moreover, as this study was the first evaluation of *SoPhy*, evaluation of the *SoPhy* socks was also essential to confirm that the socks are appropriate for use by the patients in future. Hence, I evaluated the socks for its wearability, visibility, and design. In this regard, the technical efficacy of the *SoPhy* socks was evaluated through interviews and a wearability questionnaire explained later. On the other hand, the other two parameters related to the diagnostic efficacy, i.e, *diagnostic accuracy efficacy* and *diagnostic thinking efficacy*, provided me with a lens to understand whether and how the presented information is helpful for the physiotherapists. For instance, the model includes parameters like a correction in assessment and influence on diagnostic confidence with the developed systems that helped me to understand how the diagnostic accuracy and decision-making ability of the physiotherapists changed with *SoPhy*.

The data collection started with the aim of understanding whether and how *SoPhy* helps physiotherapists in assessing patients during video consultations. The use of the efficacy model was defined later as my understanding of the utility of *SoPhy* emerged (I will explain it in the data analysis). I employed a mixed method approach and collected both qualitative and quantitative data to address the study goals. Data collection methods for this study includes the video recording of the sessions, participant observations, informal conversations, Patient Assessment Form, a questionnaire on sock wearability and semi-structured interviews. The study followed the Embedded design mixed method approach (Creswell et al., 2003), where the quantitative data offered a secondary role to support the insights gained from the qualitative data. For instance, the data captured through the *Patient Assessment Form* was utilised to support the interview data and to offer stronger pieces of evidence about the potential of *SoPhy* for physiotherapists during video consultations.

The data collection happened in two phases: during the laboratory evaluation and after the session. Table 6-6 provides a summary of the data collected in both the phases of the study. Below I describe the data collection in both phases. As shown in the table, I collected data from the participants and not from the actor because the aim of this study was to support physiotherapists in assessing patients over video consultations. However, I also gave the actor an opportunity to express her experience with *SoPhy*. The actor's insights although did not become a part of the formal data collection for the study, but were helpful in understanding the working of the socks and the associated technical issues.

Phases	Tasks for participants	Data collection methods	Time taken by the participants
During session	a. Act as a physiotherapist for four video consultations b. In each session, fill in the Patient Assessment Form for each exercise performed by the actor	a. Video recording of the session from participant end b. Participant observation c. Informal conversations d. Patient Assessment Form	15 - 20 minutes for each session (60 - 80 minutes in total)
Post session	a. Comment on the clarity of the *SoPhy* visualisations b. Try out the socks c. Fill in the questionnaire on Sock Wearability d. Comment on the overall utility of *SoPhy*	a. Audio recording of the interview b. Questionnaire on sock wearability	40 - 50 minutes

Table 6-6: Summary of the data collected across two phases of the study.

Data Collection During the Session

During the laboratory evaluation, I utilized four methods to collect rich data from the participants - video recording of the session, participant observations, informal conversations, and Patient Assessment Form. Firstly, I video-recorded the sessions from the participant end to understand the participant's interactions with the system and any issues that they faced during the session. I also conducted participant observations to understand their interactions with *SoPhy*. (Refer Appendix C.6 for the observation guide.) Being present with the participants allowed me to reflect upon the latest event in a think-aloud manner through informal conversations. Observations and informal conversations were written as field-notes. These notes were mainly taken in the text but they also had sketches related to bodily information. Appendix C.7 presents snapshots of the observations notes. Finally, I developed a questionnaire to evaluate the participant's understanding of the information presented by *SoPhy.* This questionnaire was the main source of data collection during the session. I describe the questionnaire below.

Patient Assessment Form

I designed a Patient Assessment Form to evaluate the utility of *SoPhy* for physiotherapists in understanding lower limb movements. (Appendix C.8 presents the snapshots of the form.) The form was modeled after the assessment form of the collaborating hospital and through consultation with the collaborating physiotherapist to answer the research questions. The form was framed as a Patient Assessment Form because it was intended to assess the patient's recovery and not the skills of physiotherapists. Consequently, unlike the hospital assessment form, the form was framed only around the dependent variables of the study, i.e., weight distribution, foot orientation, range of movement and confidence. For each parameter, participants were asked to record their responses on a numerical scale of 0 to 6. Apart from the study parameters, I also added 'tremor' as another bodily information in the form, to blind the participants with the study variables, and to generate discussions around what was missing in *SoPhy*. No analysis was done on this parameter.

The form became the conversational pointer to ask participants about their understanding of the bodily information. As such, it helped in channeling their thoughts on the study parameters and thereby, elicited deeper discussions during the session as well as later in the interview. As the participants were filling in the form, I encouraged them to think-aloud what they were filling in and why.

Each participant filled one form in each session (four in total). The form started by providing background information of the patient's health condition (as shown in Table 6-3 & 6-4), and required the participant to fill in the patient's pain intensity on both feet (on a scale of 0 to 6). The participant had to inquire the patient about their pain to fill in this information, which provided them with a starting point to initiate the consultation. No statistical analysis was conducted on the pain intensity scoring. This factor was included to give participants a feeling that all the four patient profiles were different.

For each exercise, participants were asked to fill in the following information for both feet: weight distribution, foot orientation, range of movement, and confidence in the assessment. For each factor, the participant marked a selection on a scale of 0 to 6. I provided labels for value 0, 3 and 6 for coded data. For weight distribution, participants assessed the pattern of weight distribution over each foot (labels: heel, middle, and balls). Similarly, participants assessed the foot orientation (labels: medially, balanced and laterally) and range of movement (labels: none, partial and complete) over each foot. Confidence assessment was a self-rated value with labels: lowest, medium, and highest. Finally, the final section was dedicated to writing notes about the body posture of the patient and a rating of confidence value with the overall assessment.

Data Collection Post Session

After the laboratory session, video recorders were switched off. In this phase, I collected data from two sources, interviews and questionnaire on sock wearability. Again, all the data was collected from the participants and not from the actor. Interviews were the main source of data collection about the overall experience of participants with *SoPhy*. On the other hand, the questionnaire on sock wearability was the only source to statistically establish the comfort of *SoPhy* socks. I describe both of them below.

Interviews

I conducted a semi-structured interview with each participant where they reflected upon their experience of using *SoPhy* to assess patients during video consultations. (Refer Appendix C.9 for the interview guide.) These interviews gave me insights on how *SoPhy* visualisation was used by participants and any issues associated with it. The interviews were facilitated by the notes taken during observations and the Patient Assessment Form. The interviews started by reviewing the Patient Assessment Form that participants filled during the session. Participants compared their assessment across four sessions and illustrated their assessment process with *SoPhy* and without *SoPhy*. They talked about how they understood the bodily information presented in *SoPhy* visualisation for different exercises listed in the form. All interviews were audio-recorded for later analysis. Towards the end of the interview, I introduced participants with the *SoPhy* socks. I asked them to wear the *SoPhy* socks and perform any exercise that they considered important for patients with lower limb issues. They were asked to comment on the comfort and potential applications of *SoPhy* for video consultations and their clinical practice in general. After trying out the socks, the participants were asked to fill in a questionnaire on sock wearability, which I describe next. Participants were encouraged to think aloud when they were filling in the questionnaire.

Questionnaire on Sock Wearability

Next, I used a questionnaire on sock wearability with the participants to evaluate their level of comfort in wearing the *SoPhy* socks. Understanding the wearability of the socks helped me to investigate the technical efficacy of *SoPhy* and any related issues. The questionnaire was used to understand any potential issues that real patients with different pain conditions may face in wearing the *SoPhy* socks in the real-world setting. Participants were first asked to wear the *SoPhy* socks and perform any lower limb exercises. They then filled in the questionnaire to describe their comfort with the socks. (Appendix C.10 provides a snapshot of the questionnaire used in the study.) The questionnaire was adopted from the prior work by Knight and colleagues (Knight et al., 2006). The questionnaire assesses user comfort with a wearable technology around six parameters – attachment, harm, perceived change, movement, and anxiety. Below I describe these parameters.

- *Emotion* - The first factor is concerned about the appearance and relaxation of the *SoPhy* socks.
- *Attachment* – This factor talks about the feel of the socks on the body either directly (e.g., socks components pressing on the body) or indirectly (e.g., in relation to body movement).
- *Harm* – This parameter concerns any physical sensation or pain caused by the socks.
- *Perceived change* – This factor is related to the non-harmful physical sensation caused by the socks that makes the user feel different about their movements or actions.
- *Movement* – This factor talks about the alterations in posture or movements that the user has adopted consciously because of the socks.
- *Anxiety* – The last parameter is related to any potential concerns that the user might have about the safety of wearing the socks, or its working of socks.

Table 6-7 lists the parameters of the questionnaire used in the study to evaluate the *SoPhy* socks. The questionnaire followed a 10-point Likert scale for the participants to mark their selection. Labels were provided on values 1 and 10, which respectively represented 'Strongly Disagree' and 'Strongly Agree'.

S.No.	Parameters of Sock Wearability	Descriptors used in the questionnaire
1	Emotions	I feel self-conscious about having people see me wear this sock
2	Attachment	I can feel the socks moving on my body
3	Harm	I feel some pain or discomfort wearing the socks
4	Perceived Change	Wearing the socks makes me feel physically different. I feel strange wearing it
5	Movement	I feel that the socks affect the way I move
6	Anxiety	I do not feel secure wearing the socks

Table 6-7: Details of the six parameters used in the questionnaire to evaluate the participants' comfort in wearing the *SoPhy* socks. These parameters were presented on a scale of 1 to 10 with 1 being 'Strongly Disagree' and 10 being 'Strongly Agree'.

6.3.5. Data Analysis

The data generated from the laboratory evaluation included: (1) Ten video recordings of the lab sessions from the participant end, (2) Ten video recordings of the lab sessions from the actor room, (3) Ten scripts from the observation notes diary, (4) Forty copies of the Patient Assessment Form, (5) Ten audio recordings of the interviews, and (6) Ten copies of the Questionnaire on Sock Wearability.

I employed thematic analysis to analyse the collected data, where I ran qualitative and quantitative analysis on different data sets. Similar to Study 1, I used both the inductive and deductive approach to iteratively code the data. Qualitative analysis was conducted to understand how participants used *SoPhy* to assess patients, and what issues they faced in using *SoPhy* during the session. Qualitative analysis was conducted on the following data resources: video recording of the session from the participant end, field notes including both participant observations and informal conversations, and interview recordings. On the other hand, quantitative analysis was performed to establish the statistical significance of the potential of *SoPhy* for physiotherapists in different aspects of assessment, e.g., in assessing different exercises, diagnostic confidence, and assessment of different bodily information. Quantitative analysis was performed on the following three datasets: video recordings of the sessions from the actor end, patient assessment form and the sock wearability questionnaire.

Getting Familiar with the Data

The first phase of getting familiarised with the data was an ongoing process throughout the study. A part of the analysis started since the beginning of the data collection, where I started reflecting on each study session. After each session, I read the observation notes and produced a summary of the session highlights in the notes diary itself. During this time, I also started coding the notes with pencil mark-ups. Depending upon this reflection, I revised the interview guide to add new questions that were not asked in that session and revise the existing ones. Similarly, I revised the observation guide to specifically look for certain activities that I felt essential to understand the utility of *SoPhy*. Secondly, I filled the data collected from the Patient Assessment Form and Questionnaire on Sock Wearability in the excel sheets immediately after the session. This exercise helped me to establish the correlation between what participants said and what they responded in the questionnaires. Finally, I watched the video recording of the participants from the study sessions to see their interactions with *SoPhy* and to refer to their comments during the session. This activity helped me to confirm my notes taken during the session. Any new insights from the video recordings became a part of the notes for that session.

Another part of this phase happened after finishing the data collection with ten participants. Firstly, I transcribed all the interview recordings manually on a computer using the Express Scribe Transcription software[19]. The manual process helped me to immerse in the data and to generate initial ideas for the emergent themes. These recordings were selectively transcribed, i.e., I transcribed only that part of the interview which was related to the research aims, and any other data not relevant to the research goals was discarded. After finishing all the transcription, the digital copy of the transcribed interviews was then printed in a hard copy to develop codes on paper. Additionally, video recordings of the actor were analysed to compare the assessment across *with SoPhy* and *without SoPhy* conditions. From these video recordings, I manually calculated the number of repetitions of each exercise performed by the actor in each session, duration of each session, number of times the actor changed the direction based on participant's request in order to demonstrate exercises. All this data was populated in the excel sheet for the statistical analysis.

At the end of this phase, I developed three excel sheets (Patient Assessment Form, Sock Wearability Questionnaire and video analysis of the actor), one hard copy of the interview data and ten scripts from the observation notes diary. This data then went through coding in the next phase.

[19] Express Scribe Transcription software http://www.nch.com.au/scribe/index.html

Coding

The next phases of thematic analysis, i.e., generating the codes, defining the themes, reviewing the themes and writing up the themes were intertwined in this study. Following the inductive approach, all the transcribed data went through several rounds of coding to find themes related to the research aims and to identify areas of improvement in the prototype. I started with reading the interview transcripts and observation notes to generate codes about the interactions with *SoPhy*. In the first pass, I coded the data with a pencil to highlight the interesting events. After a couple of readings, I generated nineteen themes to describe the data. I listed these themes on a document and coded the transcripts again, and this time directly with the theme number. I also added data from the notes diary to support these quotes, with a pen on the printed transcripts. (Appendix C.11 provides details of different passes conducted during the data coding.)

After this pass, I created a document, where I added all the participant quotations that were relevant for each theme. In the next pass, I repeatedly read this document to review the themes and the corresponding quotations in order to find out about themes that should be merged or separated. Some themes were merged in this pass, and the total number of themes became thirteen. Later, I developed another document with thirteen themes and description of relevant participant quotes and field notes data. This was the first draft of the findings. This document was discussed with my supervisors to get their feedback on the themes. In this discussion, the themes were reviewed again and following affinity diagram, the themes were merged into five themes - four related to the utility of *SoPhy* in assessment and one related to the issue faced by participants in using *SoPhy*.

After finalising the five themes for the findings, I conducted quantitative analysis on the three excel sheets. Having written up the findings, the main purpose of this analysis was to support the qualitative data with statistical inferences. To begin with, a nonparametric factorial ANOVA analysis was used to analyse the data collected from the Patient Assessment Form using the Aligned Rank Transform tool in R (Wobbrock et al., 2011). The analysis was conducted on the independent variables - *consultation technology* and *pain level*, and the interaction effect of *consultation technology*pain level* on the dependent variables: *weight distribution, foot orientation, range of movement,* and *confidence assessment*. Similarly, data collected from the video recording was analysed using ANOVA analysis. Until this stage, all the variables analysed from the video recording were dependent variables, which included exercise repetitions, duration of session, and number of direction change. Based upon this analysis, the dependent variables were refined to exclude those parameters, where no statistical significance were found. Consequently, *exercise repetition* became a dependent variable and remaining others were excluded. And finally, descriptive statistics were applied on the data collected from the sock wearability questionnaire - this data helped to determine the level of comfort of the *SoPhy* socks. This analysis was conducted using Microsoft Excel with the Analysis ToolPak add-in. (Appendix C.12 shows snapshots of the statistical analysis performed on the collected data.)

Final iteration of the findings happened during the thesis writing phase when I finished data collection of all three studies. In this iteration, the data was analysed deductively around different aspects of the efficacy model. The decision to introduce the efficacy model in this study was inspired from the conduct of Study 3, where the efficacy model was an integral part of the study design. Since this study was the prequel of the field deployments, I introduced the model in this study to make a coherent story throughout the thesis. For instance, while this study investigated how SoPhy help in the assessment, the field deployments in Study 3 investigated its utility in both assessment and treatment. Given the aims and conduct of this study, I introduced only three aspects of the efficacy model in this study, namely, technical efficacy, diagnostic accuracy efficacy and diagnostic thinking efficacy (as listed in Table 6-5). Introduction of this model did not require any restructuring or addition of new themes in the findings. I cross-checked if all the parameters of the efficacy model relevant to this study, were addressed in the findings. In this regard, I added more details to enhance the findings. Data collection and Discussion sections were also revised to link the efficacy model more closely with this study. Next, I describe the findings across five themes.

6.4. Findings

Below I discuss the findings across five themes. I used participant IDs (P1, P2 …) to denote their quotations. These ids are formulated from the session number, when the participant participated in the study.

6.4.1. Increased Confidence in Assessment

The findings show that participants were more confident in their assessment when using *SoPhy* during video consultations. For squats, there was a main effect of consultation technology on confidence ratings ($F(1,36) = 10.97$, $p<.01$). *SoPhy* increased the confidence of the participants in assessing squats (M = 5.28, SD = 1.07), as compared to the video consultations without *SoPhy* (M = 4.17, SD = 1.13) (refer to Table 6-8). No significant comparison was found for other exercises.

Participants described that squats are less obvious to understand because squats is a full body exercise and physiotherapists need to observe multiple dimensions to understand the movement. As explained by a participant, *"With the squats I would like to see all dimensions of what is going on, it's a closed chain exercise. So you have to look*

Exercises	*with SoPhy* condition	*without SoPhy* condition
Squats F(1,36) = 10.97, *p<.01*	M = 5.28, SD = 1.07	M = 4.17, SD = 1.13

Table 6-8: Participants felt more confident in assessing squats with *SoPhy*.

at the shoulders, hips, and knees all at the same time. The sock program was really handy in that regard where I could see what they are doing down there. In fact, any closed circuit where your foot is on the ground and you need to manage your weight would be benefitted by the data." (P7)

The qualitative analysis of the data revealed that *SoPhy* was critical to confirm initial observations made through the video data. All participants developed a strategy to get the required information from video stream and *SoPhy* interface. They formulated an initial assessment by first observing a couple of repetitions from the video stream and then utilized the *SoPhy* interface to verify their hypothesis: *"The sock system was more like a confirmation for me. I used the strategy of first seeing the video and then form an assessment. After a couple of repetitions with video, I used the interface to confirm my assessment."* (P8)

Apart from helping participants in validating their hypothesis, *SoPhy* also corrected their assessment by providing information that was not observable over video. One participant described how *SoPhy* corrected the assessment related to foot orientation, *"I particularly remember one time when the system really helped me. I didn't quite get the lateral position of her [patient's] foot, but the numbers on the system guided me."* (P5)

SoPhy reduced the need for verbal confirmation with patients and the ambiguity created by such dialogues. While participants sought verbal confirmation for their assessment in the consultation without *SoPhy*, e.g., *"It seems like you are not putting more weight on the outside of your left foot"* (P2), there were no such verbal confirmations with *SoPhy*. Participants described that they felt more confident in their assessment with *SoPhy*. This removed the need for verbal confirmation and potential ambiguity it may bring, as discussed by participant 2: *"I did get more confident in my assessment with the socks data. Without it, I may not be able to pick up things just from video. Like I thought, 'Oh that the foot looks tilted outside', but then whether it has any relation with their weight distribution or not, I can't tell just from the video. Confirming with the patient is not very helpful as they might not know what's going on with them."* (P2)

6.4.2. Fewer Exercise Repetitions were Required to Assess Patients

Participants reported that with *SoPhy* they needed fewer repetitions of exercises to assess patients as compared to the video consultations without *SoPhy*. The analysis of the video recordings showed that *SoPhy* required 25-30% fewer exercise repetitions for three exercises - dorsiflexion, plantarflexion and squats - than the *without SoPhy* condition, as listed in Table 6-9. For other exercises, there was no significant difference on the number of repetitions with *SoPhy.*

One reason behind the reduction in the number of exercise repetitions with *SoPhy* was the increase in the diagnostic confidence of the participants. During the interview, participants described that they had a clear picture of the patient's condition after seeing the first couple of exercises with *SoPhy*. *"With the sock system, I realized I got good information quite early, which was really good. I did not push her way too much then, which is what I will do with real patients. Therefore, I was more confident then."* (P3)

A second reason was that *SoPhy* alleviated the need to ask patients to perform exercises with different camera angles. Rather than asking patients to reposition themselves or the camera to see specific body movements, *SoPhy* offered rich information equivalent to multiple camera viewpoints: *"Over video, I can't see what's going on behind the foot, especially for exercises like plantarflexion. I can see the person only from one direction. The system provides me this detailed information irrespective of how the person is standing or sitting. Of course, you can ask the person to turn around, but unless you are right there you would not understand what is going on. I did not ask the patient to turn backwards or sideways when I had the sock data. The system was already doing it for me."* (P3)

Exercises	*with SoPhy* condition	*without SoPhy* condition
Dorsiflexion F(1,36) = 6.99, *p<.05*	M = 8.10, SD = 3.21	M = 11.45, SD = 4.54
Plantarflexion F(1,36) = 6.14, *p<.05*	M = 7.45, SD = 3.88	M = 10.60, SD = 4.24
Squats F(1,36) = 8.36, *p<.01*	M = 6.05, SD = 2.48	M = 8.05, SD = 3.18

Table 6-9: With *SoPhy,* participants required fewer repetitions to assess three exercises – dorsiflexion, plantarflexion and squats.

Reduction in the number of repetitions is important especially, for patients in extreme pain, as it helps clinicians to avoid movements that could inflict further pain to the patient. *"If a person is in extreme pain, I wouldn't ask them to do more exercise. I wouldn't want them to keep going, or otherwise, they will lose trust in the therapy."* (P3)

6.4.3. Weight Distribution Offered Hitherto Unavailable Insights

SoPhy was appreciated most for offering information related to weight distribution, as weight distribution is always challenging to observe through naked eyes. Participants had never seen this information earlier and therefore, they appreciated *SoPhy* as a novel system. Information about range of movement also helped participants in understanding the patient's issues, but it was largely inferred from the video stream. For range, *SoPhy* mainly offered an objective measure to assess the patient particularly in situations when both feet are injured: *"Range is always about comparison. We compare the range of affected foot with the other good side. But when both feet are affected, it makes things little bit harder. You don't know what is their normal range. Having these numbers will help me in comparing the absolute range of each foot."* (P10)

Participants described that, unlike the range of movement, there is no direct way to observe the weight distribution: *"We use Goniometer to measure the range of motion for every joint and Dynamometer to measure grip strength in the clinic. But there is no tool to measure the weight distribution."* (P4). They described observing other clues to understand weight distribution during face-to-face assessments, e.g., *"from the noise patients are making while walking"* (P5). However, such clues vary based on different factors (e.g., shoe sole, and weight bearing) and are difficult to observe over video. Hence, the weight information provided by *SoPhy* offered a direct way to assess patients. The visualisation not only helped them to understand which foot is bearing more weight, but also how much weight is distributed across each foot. *"It's always challenging to understand weight bearing because the pressure points are not visible. The socks data certainly helped in that way. It's easy in cases when the person is putting more weight on one foot than other. But it is difficult to understand how the weight is distributed across the foot, is it on the heels, or on the balls."* (P8)

Moreover, weight distribution was also considered sufficient to understand the information related to the foot orientation. Only those foot orientations were expressed critical that has association with the weight bearing. In this regard, *SoPhy* offered details of lateral and medial orientations that are difficult to eyeball. One participant described the difficulty that she faced in checking the foot orientation in sessions without *SoPhy*: *"When I asked the patient to turn sideways to see the lateral and medial alignment of the foot, the front leg obstructs the other leg. It's harder to see both legs at the same* *time from here [at the other end of video call].”* (P7) Another participant described how *SoPhy* helped him to understand these orientations: *“The values of weight distribution were sufficient for me to know that the person is moving laterally or medially. The numbers tell me that the person has pressure on the outside, inside or at the back. So then visually I can get that if the pressure is on the outside, meaning she is going laterally.”* (P10)

Participants considered *SoPhy* as a valuable tool for making real-time assessment of weight distribution. They appreciated the mobility offered by *SoPhy* and compared it with the gait lab where physiotherapists typically assess patient's movements: *“Normally we do gait analysis in the dedicated lab, which is a bit complex setup that requires arrangement in terms of booking the lab, understanding the system, and it's not always accessible. The socks system is a great example of a mobile gait lab. I can see their biomechanics related to walking, and exercising in real-time.”* (P6) The statistical analysis further underlined the difficulty of assessing weight distribution and the difference that *SoPhy* makes. The analysis showed that there is a significant difference in assessing the lateral and medial orientation of the affected foot between *with SoPhy* and *without SoPhy* conditions for the following three exercises: dorsiflexion ($F(1,36) = 4.30$, $p<.05$), double leg heel raises ($F(1,36) = 7.63$, $p<.01$) and single leg heel raises ($F(1,36) = 25.50$, $p<.001$). (The mean and standard deviation values are not shown in this case because a higher value for orientation does not mean anything, unlike a higher value for confidence and exercise repetitions.)

The interaction effect between consultation technology and pain level was significant for the medial and lateral orientation factor for dorsiflexion ($F(1,36) = 4.30$, $p<.05$) and squats ($F(1,36) = 12.70$, $p<.01$). I then performed two Wilcoxon signed-rank tests using Bonferroni adjusted alpha level of 0.025 per test (.05/2), to analyse the effect of *SoPhy* within each pain level for dorsiflexion and squats. For squats, there was a main effect of *SoPhy* on assessing the orientation in *extreme pain* condition, ($Z = 3.92$, $p<.025$). There was no other significant pairwise comparison found. It is important to note that the results do not indicate the assessment being more accurate, as there is no benchmark to make this comparison. However, the difference in the assessment highlights that *SoPhy* did not merely confirm assessments made via video, but that it also helped in assessing weight distribution for different foot orientations.

6.4.4. Pain Levels Influenced Assessment with SoPhy

The level of pain experienced by patients is an important factor for physiotherapists because it affects their choice of exercises and the corresponding number of repetitions to recommend to the patient. I found that the pain level had significant effects on orientation assessment throughout all exercises: dorsiflexion ($F(1,36) = 27.70$, $p<.001$), plantarflexion ($F(1,36) = 29.90$, $p<.001$), squats ($F(1,36) = 9.75$, $p<.01$), double leg heel raises ($F(1,36) = 30.06$, $p<.001$) and single leg heel raises ($F(1,36) = 20.06$, $p<.001$). This finding mainly validates that the actor consistently performed the patient profiles because patient profiles for extreme pain had injury in their left foot, whereas patients with low pain profiles had right foot injury.

Participants stated that they used *SoPhy* differently depending on the pain condition. In extreme pain condition, physiotherapists focus more on the training and motivating the patient to perform movements, where *SoPhy* could be used as a feedback tool for patients: *"In extreme pain, the system might be more useful for patients to see what's happening. So, they could see that they are scoring 3 on that affected area whereas it's 18 on the other foot for the same location. In pain, quite a lot of sensations get mixed up and they are not able to distinguish the difference. Now through numbers, you can talk through what they are doing as opposed to what they should be doing."* (P5)

For low pain condition, participants described that the aim of physiotherapists is to optimize patient's movements with focus on subtleties, such that they could get back to their normal movements. Here, *SoPhy* will help in making comparisons on the patient's recovery. One participant highlighted the challenge of bringing the patient back to the normal movements and how *SoPhy* would be helpful: *"In pain, people change the biomechanics of their body to allow them to do different activities. They might have developed some secondary changes down the road. Like to walk, they kind of hit the ground and then pull the foot in some sort of fashion. It's harder to eyeball all these tricks, and you can't even confirm it with the patient. That's where the numbers [from SoPhy] will help me to see whether there is any improvement in the patterns or not."* (P10)

Irrespective of the pain conditions, participants found that the visualisation provided on *SoPhy* interface offer crucial feedback to patients. They described that visual feedback is very important for patients as it helps them to understand what they are doing as opposed to what they should be doing: *"Patients need to get a better intuitive understanding of their movements because when you understand something intuitively, then it becomes easier to do. This system will indeed provide them the required visual push to keep them moving."* (P10)

The analysis of the questionnaire on sock wearability also established that patients could wear the *SoPhy* socks across different pain conditions. Table 6-10 presents the descriptive statistics on the questionnaire. The analysis showed that the mean values of all six parameters are less than 2, which means that there is low discomfort associated with wearing the *SoPhy* socks. Participants did not perceive any harm for patients in using the socks for rehabilitation purposes. Also, they did not find the socks as an external attachment that could adversely influence patient's movements. As such, the *SoPhy* socks were found comparable to the normal socks.

	Emotions	Attachment	Harm	Perceived Change	Movement	Anxiety
Mean & Standard Deviation	M = 1.4, SD = 0.7	M = 1.4, SD = 0.52	M = 1.1, SD = 0.31	M = 1.8, SD = 1.03	M = 1.7, SD = 0.95	M = 1.6, SD = 1.07

Table 6-10: Descriptive statistics conducted on the questionnaire of sock wearability for ten participants: Mean value for all the parameters is less than 2, indicating that *SoPhy* is wearable.

6.4.5. Technical Difficulties in Using SoPhy

The study also highlighted several challenges in interpreting the information provided by *SoPhy* with observations from the video. Several participants reported that it took them a while to learn how the system works and how to relate the information presented by *SoPhy* to the information gleaned from the video. *"It was a little bit distracting in the beginning when you don't know what to see when. I spent too much time looking at the numbers without much looking at what the patient was doing."* (P10)

The main challenge was to map the information offered by *SoPhy* with the movements visible over video stream. The visualisations offered by *SoPhy* were presented on a different screen to the video and simply looking at the visualisation did not provide sufficient information. Mapping the visualisation with movements was particularly difficult for dynamic exercises like walking: *"When she was walking, I wanted to see her gait but I also wanted to check the numbers. But when I see the numbers on the other screen, it is difficult for me to understand what data corresponds to which movement."* (P7)

Mapping left and right foot on the video stream and on the *SoPhy* interface created confusion for the participants. For instance, on Skype, the orientation of people at both ends is opposite such that the left foot of the patient is the right foot of the physiotherapist. *SoPhy* web interface follows the same order of the patient's feet as visible to physiotherapists over video, i.e., right foot followed by the left foot (Refer Figure 6-6). To understand patient's movements, participants first mapped their observations from video stream to their left and right feet, then they did the mapping again to read the *SoPhy* web-interface, and finally, they repeated the same mapping to fill out the Patient Assessment Form: *"Mapping the left and the right side is the biggest challenge like in video the right foot of the patient is my left foot. And then on the other screen [SoPhy interface], I need to do this mapping again."* (P4)

Moreover, the presentation of the range of movement further added to the confusion. *SoPhy* interface presented a flexion degree (a number between 0-10) to present the

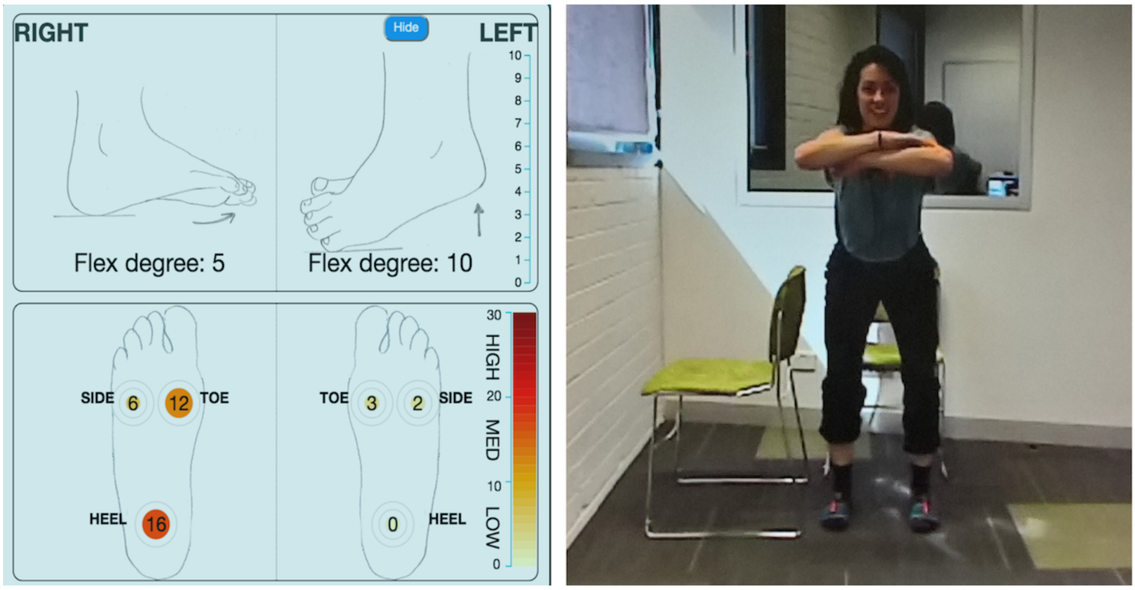


Figure 6-6: *SoPhy* web-interface presented the visualisation in the same order as the patient was seen in the video stream. However, this sequence created confusion in mapping the movements amongst the participants.

range, whereas participants measure the range as an angular displacement (e.g., 70 degrees) from the starting point to the end of a given movement. *"Right now, the system gives me some numbers for range. I do not know what these numbers are, whether it's positive or negative like dorsi data is a positive angle for me, while the plantar angle is negative."* (P10)

Finally, for some participants the sock was interfering with their observations from the video. While the sock helped in capturing new information, it also concealed information about the foot structure that participants could observe in the standard video consultation without *SoPhy*. *"The biggest issue with a sock is that it covers the foot and it is hard to see the foot moving. With socks, you see the foot as a plank but there are so many joints moving for one movement. Not being able to see the foot may not be an issue for all conditions, it is more important for injuries in toe as you might want to see how the toe is placed, or is it moving at all or not."* (P6)

6.5. Discussion

The study investigated whether and how *SoPhy* influence the efficacy of physiotherapists in assessing patients with lower limb issues in video consultations organised in a laboratory setting. The study showed that *SoPhy* provided essential information about the patient's lower limb movements to physiotherapist that helped them to take informed-decision about the patient's condition. Participants considered the information presented by *SoPhy* equivalent to having multiple camera viewpoints, which in turn expanded patient's field-of-view and offered rich understanding of the patient's movements. They utilised *SoPhy* as a tool to confirm their assessment. They first formulated an initial assessment of the patient's condition by observing the patient's movements through the video stream, and then utilised the *SoPhy* visualisation to validate their assessment. Getting confirmation from *SoPhy* boosted their confidence in their assessment.

In response to the first sub-question (Q1), *SoPhy* enhanced the diagnostic efficacy of physiotherapists in assessing patients during video consultations by improving their diagnostic thinking ability and accuracy. I will now discuss how *SoPhy* fulfilled different parameters of the diagnostic efficacy as listed in Table 6-5. Firstly, the study showed that *SoPhy* improved the diagnostic thinking efficacy of the physiotherapists by providing them the essential information related to lower limb movements of the patients. *SoPhy* helped them to get confirmation on their assessment, which boosted their confidence in assessing patients. Consequently, participants did not seek verbal confirmation from the patients on their assessment, which participants appreciated because patients themselves are not aware of their condition. The statistical analysis also showed that participants felt more confident in assessing squats exercises with *SoPhy* (refer Table 6-8). Increased confidence in assessment is crucial because it impacts the consecutive diagnosis and treatment of the patient, which in turn, increases the patient's trust in the treatment (Demiris et al., 2010; Stewart, 1995).

The rich information provided by *SoPhy* helped physiotherapists to assess different exercises of the patients. *SoPhy* was particularly appreciated to assess weight bearing exercises like squats, heel raises and walking, than to assess other exercises like dorsiflexion and plantarflexion. Participants described that weight bearing exercises involve multiple parameters that physiotherapists need to observe, e.g., movements of the shoulder, hips and thighs, and most critically the patient's strategy to distribute weight. The real-time information of weight distribution and foot orientation, thus offered a crucial information that participants were able to better understand the patient's recovery. While on the other hand, exercises like dorsiflexion and plantarflexion are comparatively easier to understand as it involves observation of only range of movement, while the whole body is at rest. Even for these exercises, the information of range of movement was useful as it reduced the participants need to request rearrangement of the camera or the patient, to get required perspective on the movements. This was also confirmed by the statistical analysis, which showed that participants requested fewer repetitions to assess three exercises - dorsiflexion, plantarflexion and squats when using *SoPhy* (refer Table 6-9). Ability to assess patients in fewer repetitions is helpful in extreme pain conditions, as physiotherapists can get a good understanding of the patient's condition without causing them much discomfort.

Additionally, the study also showed that *SoPhy* improved the diagnostic accuracy of the participants by correcting their hypothesis at certain instances. The visualisation revealed subtle differences in the patient's movements that were not distinguishable over video. Participants described being more clear about the patient's weight bearing pattern through *SoPhy* visualisation. The statistical analysis also showed that *SoPhy* helped the participants to better understand the differences in the patient's foot orientations such as medial and lateral orientations for three exercises- dorsiflexion, single leg heel raises and double leg heel raises. Besides being a useful tool for physiotherapists, the study also highlighted the potential benefits of *SoPhy* for patients. Participants described that *SoPhy* visualisation could offer crucial feedback to patients on their movements, which is essential as patients usually are not aware of their movements. The visualisation could help patients in knowing what they should be doing as opposed to what they were doing, e.g., how to distribute their weight while using crutches.

With regards to the *technical efficacy* of *SoPhy* (Q2), the study both positive and negative aspects of the *SoPhy* visualisation and socks. Firstly, the study showed that the three parameters supported by *SoPhy* are sufficient to assess lower limb movements. Information related to the weight distribution was described as the most useful and novel information that participants had never seen either in face-to-face or video consultation settings. This is novel because the existing literature in HCI on rehabilitation technologies mainly highlight the importance of range of movements, e.g., for knee movements (Ananthanarayan et al., 2013; Ayoade and Baillie, 2014; Lam et al., 2016) or shoulder movements (Tang et al., 2015). Physiotherapists cannot directly observe weight distribution in video consultations. Hence, seeing weight distribution not only between the feet but also across each foot provided detailed information to assess patient's movements. Additionally, the information related to weight distribution was also sufficient to understand the patient's foot orientation. Owing to the detailed information of weight distribution that *SoPhy* offers in real-time, participants described *SoPhy* as a 'mobile gait lab' to assess both dynamic (e.g., walking) and static movements (e.g., squats, heel raises and lunges). Real-time assessment of weight distribution is limited in the current practise of physiotherapy, as it requires expertise and access to the dedicated gait lab at the hospital.

Moreover, through the range of movement, *SoPhy* added objectivity to the clinical practice of physiotherapists as they can assess the absolute range of the patient's feet. In the current practice of physiotherapy, the range of movement is a relative measure. Physiotherapists assess the foot range of the patients by comparing the movements of the affected foot with the good foot. However, such a comparison is not possible always, for example in situations when both feet are affected. And finally, regarding the technical efficacy of the *SoPhy* socks, participants described the socks comfortable to wear and found them similar to the normal socks. This was also established by the statistical analysis of the wearability questionnaire (as listed in Table 6-12). These results indicate that the socks are fine to be worn by patients in different pain conditions in the real-world setting. However, the study highlighted issues related to the visibility and the design of the socks, which I will discuss in the next section on design considerations.

With regards to the third sub-question (Q3) on improving the *technical efficacy* of *SoPhy*, the study showed that *SoPhy* requires further iteration to make it a suitable system for video consultations. Participants described certain issues with both the visualisation and the socks. For instance, the visualisation of range of movement did not overlap with the clinical practise of physiotherapists. On the other hand, the study also highlighted certain challenges of using wearable technologies like *SoPhy* in physiotherapy related video consultations. As an example, wearable technologies can limit the ability of physiotherapists in conducting visual assessment of the patients by covering the body. Another challenge relates to how physiotherapists can effectively manage reading the visualisation and the ongoing conversation with the patient during video consultations. I will discuss the implications of using a wearable technology in video consultations and the key factors for designing such systems in the next section.

6.5.1. Design Considerations

While the study revealed benefits of *SoPhy* in supporting physiotherapists during video consultations, it also highlighted certain issues in the design of *SoPhy* visualisation and socks. Below I offer three design considerations to address these issues, and to highlight how *SoPhy* can be integrated in the clinical practice of physiotherapists.

Spatial Alignment between Visualisation and Video Stream

I found that although participants appreciated the support of *SoPhy* in assessing patients, they found it challenging to comprehend the information along with the ongoing video call. Interpreting the information required constant mapping between what the patient's exercises (video stream) and *SoPhy* visualisation (another screen). Hence, participants were required to manage two screens simultaneously. Mapping the information was particularly difficult for dynamic movements like walking because the data points on both screen were changing quickly. Participants also described the problem of split attention where looking at the web-interface made them feel being ignorant or rude to the patient. However, as clinicians are effectively using screens during face-to-face consultations (Chen et al., 2011), managing two screens during video consultations might not be a major issue with repeated exposure to *SoPhy*.

More research is required to present the data such that the physiotherapists can easily incorporate the visualisation as part of their assessment. One possible approach could be to overlay the information on top of the video such that the required information is presented alongside the respective body part. However, it may grab continuous attention from clinicians even at times when they want to focus only on the video stream – which may not be the case when the visualisation is presented on a separate screen as clinicians can ignore it whenever required. Additionally, instead of presenting all the data at every time to clinicians, the system can also present selective information to clinicians based on their needs. For instance, the system could only present the unexpected patterns such as sudden change (peaks or lows) in the weight distribution or range of movement. In this regard, audio and tactile information could offer significant potential as these media have been used in the past to effectively present the data (Singh et al., 2016; Watanabe et al., 2005). Also, as found in the first study that clinicians refer to different bodily cues across different phases of the consultation, the web-interface can also be customized to fulfil different needs at different times of the consultation.

Align Visualisation with the Clinical Practice

The study highlighted issues related to the representation of the range of movement, as the provided information did not match with the clinical practice. Physiotherapists measure the range as angular movements of the joints using a device called Goniometer, whereas *SoPhy* presented this information as a value between 0-10 for foot displacements from the ground. On the other hand, the representation of weight distribution was substantially appreciated. Participants appreciated the use of different colors, numbers and the foot sketch showing the feet from underneath. Since the information related to weight distribution was new for participants, the presented information did not contradict with their prior clinical knowledge. This highlights that either the information presented by the technology should confirm with the underlying knowledge of the clinicians or it should set new defaults. The new representation may, however, involve a learning curve for clinicians to embrace the information as part of their clinical practice.

Like other sensing technologies, another important aspect of *SoPhy* is calibration (Johnson et al., 2013). *SoPhy* web-interface needs to be calibrated for different patients as the weight distribution and range of movement will vary for different people. For instance, if the weight scale of 0-30 is calibrated for a person weighing 60 kilograms; it will not show the dark red color for a person weighing 40 kilograms. Similarly, different people may have a different range of dorsiflexion and plantarflexion. On the other hand, calibration can be provided to clinicians as a functionality to integrate into the therapy. They can adjust the scale of the range of movement, for example, as a goal that the patient should achieve in a two weeks time.

Reveal Foot Structure with Wearable Technology

The study also revealed some challenges in designing the right socks for physiotherapy assessment. For example, being a wearable technology, *SoPhy* socks restricted participants' ability to visually assess the patient's foot. The loose fitting of *SoPhy* socks concealed the foot contours and foot arch that participants wanted to observe from the video stream. This issue became more prevalent for toe injury (in the extreme pain profile), where the visual examination of the barefoot was critical to assess the weight bearing on each toe.

Although it is a challenge to reveal the foot structure with wearable technology like *SoPhy*, technology can be designed differently to suit the clinical requirement. For instance, for patients with toe injuries, 5-toed socks or toeless socks might be a good design as physiotherapists can see weight bearing for each toe. For other conditions, it might be good to use the *SoPhy* socks only for a part of the session to support the assessment or treatment. Another important factor to be considered would be the type of material used for *SoPhy* socks. A body fitting socks made up of a stretch fabric like spandex could be utilized to make the foot contours visible. However, such body-fitting material may cause discomfort for certain patients e.g., those having the swollen foot.

The third factor is the socks color such that the movements are distinguishable over video. The study highlighted that the grey colored *SoPhy* socks merged with the carpet color, making the movements less interpretable over the video stream. Using bright-colored socks could make the movements distinguishable across different environments. And finally, the last key factor is the size of socks as one size *SoPhy* will not work for all. Accuracy of sensor readings will depend upon the fitting of the socks on feet. Hence, different size socks need to be designed for different sized foot. Designing *SoPhy* socks for different clinical conditions is increasingly becoming feasible given the advancements in smart textiles like FlexTiles (Parzer et al., 2016), where sensors are as fine as threads of the textile.

6.5.2. Study Limitations

Being conducted in a controlled environment in the lab, the study has certain limitations. Firstly, the study participants had no prior experience with video consultations. Thus, the generated findings may differ in the real-world settings with the experienced physiotherapists. Secondly, *SoPhy* was tested for two pain conditions – extreme and low pain, with both of them limited to injury in only one foot. In the real-world settings, patients could exhibit a wide range of health conditions, e.g., injury in both feet, injury in knee or other lower body parts with variations in pain conditions. In this regard, the generated findings may not be directly applicable to all patient conditions. Finally, this study was structured only around the assessment of patients, with the process structured around the Patient Assessment Form. The followed assessment process does not truly represent the real world assessment because assessment in real consultations happens throughout the consultation. For instance, as seen in Study 1 (Chapter 4), the physiotherapists started their assessment as soon as they see the patient and they continued to observe the patient's movements until the end of the session. Despite these limitations, the study findings are crucial to understand the implications of *SoPhy* in supporting the tasks of physiotherapists. I will confirm and extend these findings through the field deployments of *SoPhy,* described in the next chapter.

6.6. Summary of Contributions

This chapter makes the following three contributions:

1. The first contribution of this chapter is the empirical evaluation of *SoPhy* in a laboratory setting. By utilising the efficacy model, I demonstrated that *SoPhy* is a useful tool for physiotherapists to assess patients with lower limb issues in video consultations. *SoPhy* increased the diagnostic confidence of physiotherapists by providing rich information about the bodily movement. To the best of my knowledge, this is the first study that investigates the role of a wearable technology to support physiotherapists during video consultations.

2. The study highlighted the importance of weight distribution in the clinical practice of physiotherapists to understand the recovery of patients. This is novel in HCI literature because the HCI literature mainly highlights the value of the range of movement for lower limb rehabilitation (Ananthanarayan et al., 2013; Ayoade and Baillie, 2014; Lam et al., 2016). Understanding how the patient is distributing weight on their foot is significantly challenging to observe not only in face-to-face consultations but more so in standard video consultations. Information about weight distribution also provides details of the patient's foot orientation. To this end, participants appreciated the real-time capability of *SoPhy* to demonstrate changes in the weight distribution and the mobile aspect of the socks, which made it an important tool to assess a variety of weight bearing exercises like squats, heel raises and walking.

3. Finally, I listed three design considerations related to the spatial arrangement of visualisation with respect to the video stream, alignment of visualisations with the clinical practice, and revealing the body structure with wearable technology. These design considerations illustrate ways to integrate wearable technologies like *SoPhy* in clinical practices of physiotherapists.

6.7. Conclusion of Study 2

In this chapter, I evaluated how *SoPhy* enhance the ability of physiotherapists in conducting lower limb assessment during video consultations. Through the laboratory evaluation, I found that *SoPhy* increased participants' confidence in assessing the lower limb movements of patients particularly for squats exercise. *SoPhy* offered invaluable insights related to weight distribution that is neither available in standard video consultation nor in traditional face-to-face settings. Participants found *SoPhy* useful in assessing both extreme and low pain patients, where *SoPhy* could serve as a training and feedback tool. Furthermore, participants appreciated the mobility and low setup requirements of *SoPhy* that are beneficial in making the real-time assessment of weight bearing exercises such as squats and walking. Finally, the study also highlighted certain challenges related to the design of *SoPhy* interface and socks, which guided the next iteration of *SoPhy*. I will describe the revised design of *SoPhy* at the beginning of the next chapter.

After evaluating *SoPhy* in the lab setting, the next step is to investigate the utility of *SoPhy* in the real-world setting, when video consultations are organised for real patients by their physiotherapists. Following the insights from this study, *SoPhy* could also have potential in helping the patients by providing them with feedback on their movements. Consequently, in the next study, I not only investigate how *SoPhy* helps the physiotherapists in assessing and treating patients during video consultations but also explores whether and how *SoPhy* helps the patients in their therapy. To answer these questions, I conducted field deployments of *SoPhy* with the patients and physiotherapists at Royal Children's Hospital. The details of the study are discussed in the next chapter.

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Chapter 7
Study 3: Field Deployments of SoPhy

Overview: This chapter presents the final study of the thesis with details on the study procedure, findings and implications of findings with respect to Study 1 and the existing literature.

Media Coverage: This study was the winner of the Fresh Science Award 2017 in Victoria. As the award winner, the study findings were covered by more than 200 media outlets in Australia and overseas. Key highlights of the coverage include video coverage on BBC news, Ten News, ABC News, 7 News, and London Science Museum.

7.1. Introduction

The previous chapter presented the laboratory evaluation of *SoPhy* with postgraduate physiotherapy students recruited from the university campus. The study highlighted the potential of *SoPhy* in helping physiotherapists in video consultations, as it increased the diagnostic confidence of physiotherapy students in assessing patients with lower limb issues. The study also revealed certain issues with *SoPhy* based on which *SoPhy* went through another round of iteration – the details of the revision are provided at the beginning of this chapter. This chapter takes the next step to the laboratory evaluation and evaluates *SoPhy* in the hospital setting through field deployments. The aim of the field deployments is to understand the clinical efficacy of *SoPhy* for assessing and treating lower limb issues in video consultations. The study was conducted with the patients and physiotherapists at the Royal Children's Hospital in Melbourne.

The chapter starts by stating the study aims in Section 7.2. Section 7.3 provides details of the revised design of *SoPhy*. Section 7.4 describes the overall study methodology with the description of the study design, participants, and methods followed for data collection and analysis. Section 7.5 describes the study findings across six phases of video consultations. Section 7.6 provides a discussion of the study findings. Section 7.7 provides a summary of the study contributions with Section 7.8 concluding the chapter.

7.2. Study Aims

This study was conducted in response to the final research question of the thesis on:

RQ3:	How does *SoPhy* influence the efficacy of physiotherapists in assessing and treating lower limb movements in hospital video consultations?

I divided the main research question into the following related sub-questions that guided my data collection for the study:

Q1. How does *SoPhy* contribute to the diagnostic efficacy of physiotherapists?

Q2. How does *SoPhy* contribute to the therapeutic efficacy of physiotherapists?

As therapeutic efficacy is dependent upon the patient's participation, the final sub-question is:

Q3. How does *SoPhy* contribute to the patient outcome efficacy?

To address the research question and the sub-questions, I utilised qualitative approach to collect data from the field about the use of *SoPhy*. I deployed *SoPhy* in both video and face-to-face consultations at the Royal Children's Hospital in Melbourne. The decision behind deploying *SoPhy* in face-to-face consultations was consistent with the hospital protocol, where new artifacts were introduced to patients by their clinicians in face-to-face consultations. Ethics to conduct this study was approved by the ethics committee of the hospital, HREC# 36312A. (Refer Appendix D.1 to check the information letter and consent forms for clinicians and patients.) Before going into the details of the study design and findings, I will first describe the changes made in the *SoPhy* socks and web-interface based around the laboratory evaluation of *SoPhy*.

7.3. Revised Design of SoPhy

As seen in the previous chapter, Study 2 exposed certain issues related to *SoPhy*, which inspired the further iteration of the *SoPhy* socks and web-interface. Table 7-1 provides a summary of the changes made in *SoPhy* corresponding to different design goals. The revision was conducted in collaboration with the same multidisciplinary team who was involved in the development of *SoPhy* since the beginning (refer Chapter 5 for details on the design of *SoPhy*). Additionally, this phase also involved an IT professional, *Kun Liu* who was hired to refine the web-interface and server connections to ensure smooth working of *SoPhy*.

Revision in the design of *SoPhy*	Design Goals	Summary of Revisions
Iterations in the *SoPhy* socks	Reveal foot structure with wearable technology	○ Developed different sized socks for proper fitting ○ Used bright color socks to highlight foot movements against the carpet color
	Improving the aesthetics	○ All the electronics items were covered underneath different layers of cloth
Iterations in the *SoPhy* web-interface	Align visualisation with the clinical practice	○ Revised the measurement of range of movement from numerical values to angular movements ○ Discarded the visualisation of foot orientation, as the information is partly provided by the other two visualisations on weight distribution and range of movement
	Spatial alignment between visualisation and video stream	○ Changed the mapping of the foot to the left and right foot for both visualisations ○ Changed the orientation of foot sketches to represent the range of movement to allow easy comparison
	Improving the readability of visualisation	○ Removed the sensor values for weight distribution visualisation ○ Developed only the outline of foot in the foot sketches for the range of movement

Table 7-1: Revision of the *SoPhy* socks and web-interface around the design considerations discussed in Chapter 6 (Section 6.5.1).

The revision of *SoPhy* started with a 2-hour brainstorming session with one of my supervisors, *Dr Thuong Hoang*, where the changes required in the socks and web-interface were discussed. The discussion was structured around the three design considerations that emerged from the laboratory evaluation of SoPhy - '*Reveal foot* *structure with wearable technology*', '*Spatial alignment between visualisation and video stream*', and '*Align visualisation with the clinical practice*' (Section 6.5.1). Following the discussion, I prepared the list of the potential changes in *SoPhy* and then organised a brainstorming session with the collaborating physiotherapist. The discussion with the physiotherapist lasted for 2.5 hours and was facilitated through paper prototypes on potential ideas, a pair of toeless socks for discussion, existing version of the *SoPhy* socks and interface, and a short video on the working of *SoPhy.* Along with the listed issues, I also discussed other changes that were required to prepare *SoPhy* for the field deployments at the hospital, e.g., the look and feel of the socks. These issues were listed as another design goal of *'Improving the aesthetics'* for the iteration. Finally, I organised a 2-hour meeting with an interaction designer from the surrounding research community to discuss the potential changes in the web-interface. This discussion raised other essential revisions in the web-interface to make the design more intuitive and easy to interpret in real-time. These requirements were formulated under the design goal of *'Improving the readability of visualisation'*.

These discussions were formulated as five design goals – two were related to the *SoPhy* socks and the remaining three corresponded to the *SoPhy* web-interface (refer to Table 7-1). Next, I will describe the refinement in *SoPhy* socks and web-interface around the design goals. I will discuss the points discussed with the physiotherapist and the interaction designer below while describing the revisions. The final revised design of *SoPhy* was tested with the collaborating physiotherapist through mock video consultations organised across two rooms at the hospital (see details on Pilot Sessions in Section 7.4.6).

7.3.1 Refinement in the SoPhy Socks

Below I will discuss how the *SoPhy* socks were refined around two design goals, namely, Reveal foot structure with wearable technology and improving the aesthetics.

Reveal Foot Structure with Wearable Technology

Under this design goal, I started with the idea of developing toeless socks having a non-slippery sole (as shown in Figure 7-1). This idea was inspired by the issue reported in Study 2, where the socks concealed the structure of the foot and participants could not observe the movements of each toe of the patients. However, the physiotherapist raised an issue with the use of toeless socks. He described that patients typically have swollen feet and the toeless socks would not have a proper fitting on their foot, which would generate inaccurate sensor data. He also mentioned that the solid grips attached to the sole of the socks will not be perceived as comfortable by chronic pain patients, particularly those who have Complex Regional Pain Syndrome (CRPS) condition. Hence, I selected normal socks to develop *SoPhy.* In order to reveal the contours of the foot

Figure 7-1: A snapshot of the toeless socks that was used to facilitate the meeting with the collaborating physiotherapist.

through *SoPhy* socks, I chose stretchable socks made of cotton material. Finally, to achieve proper fitting of the socks on the patient's foot, I developed two sizes of socks- medium and large.

Another design decision to iterate the *SoPhy* socks was taken with regards to the color of the socks. Study 2 highlighted that the grey colored *SoPhy* socks merged with the carpet color of the room and made it difficult for physiotherapists to understand the patient's movements particularly for extreme pain profiles as the movements were very little. Therefore, I utilised bright colored socks (such as blue and pink) to make the patient's movements visible over video. These bright colors were selected by considering the guidelines on suitable colors for video conferencing[20]. Figure 7-2b shows the revised version of the *SoPhy* socks.

Improving the Aesthetics

The final change in the socks included covering the electronic components such as Bluetooth shield and conductive threads, underneath different layers of cloth. This was done to make patients comfortable in trying out the socks without scaring them with electronic items. Figure 7-2 shows the revised socks in comparison to the old socks that were used in Study 2 for laboratory evaluation.

[20] Dressing for the camera. https://wistia.com/blog/wearing-color-camera

Figure 7-2: Revision of the *SoPhy* socks: (a) The earlier version of the socks were grey in color (b) The final *SoPhy* socks are developed using bright colors.

7.3.2. Refinement in the SoPhy Visualisation

The *SoPhy* visualisation was refined around the following three design goals:

Align Visualisation with Clinical Practise

This design goal guided two revisions in the web-interface. Firstly, the visualisation of the range of movement was revised to present the foot movement in the form of angular displacement. This decision was taken in consideration with the issue revealed in Study 2, where the presneting the range of foot movement data as numerical values did not match with the clinical practice of the physiotherapists. The collaborating physiotherapist confirmed that the range of movement is only associated with the plantar and dorsiflexion, and not with lateral and medial orientations. He also described different ways in which the angle of foot range is measured through Goniometer, e.g., it could be measured taking a flat surface as axis (Figure 7-3a), or a point on the heel (Figure 7-3b), or a point under the ankle joint (refer Figure 7-3c). The key idea is that the point of reference should be static to allow correct measurement through Goniometer (Attridge, 2008). Additionally, the maximum degrees of dorsiflexion and plantarflexion differ based upon the point of reference. However, for a healthy person, dorsiflexion varies between 20-30 degrees, and the values of plantarflexion lie in between 20- 50 degrees (ibid.).

For *SoPhy*, since the IMU sensor is placed on the bridge of the foot, which does not move with the foot movements, he confirmed that it will provide accurate readings of the foot movements. (Movements in the foot happen around the ankle joint and in the forefoot having toes but not around the bridge.) Also, since both feet have the same

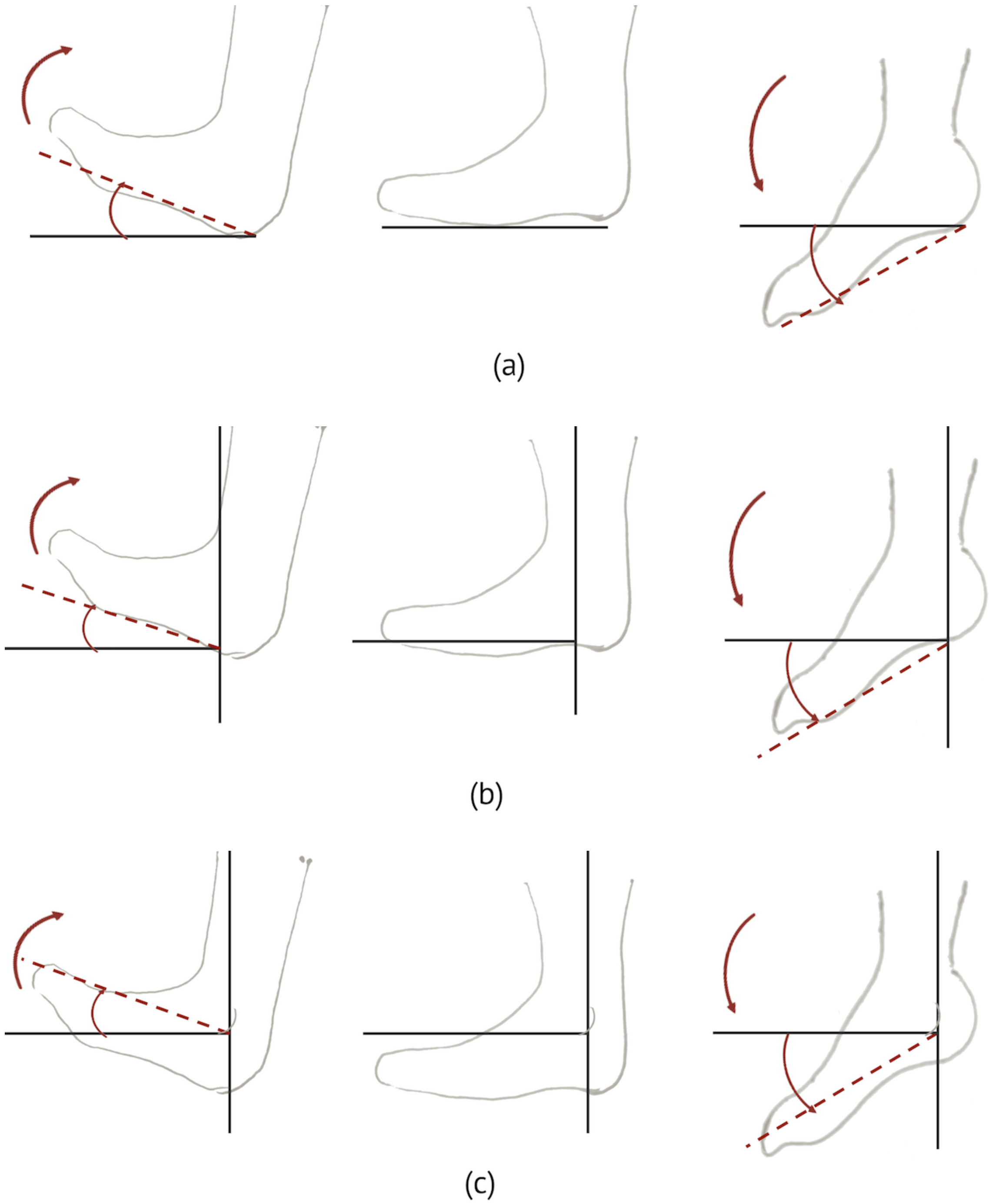
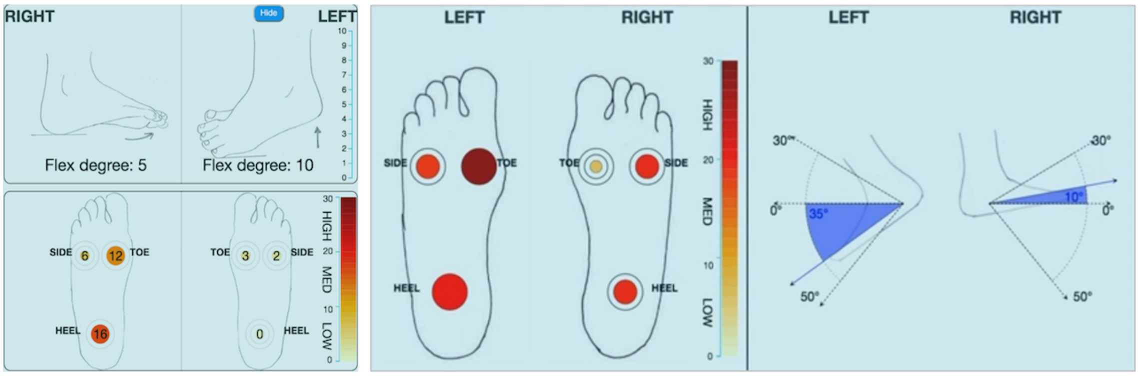


Figure 7-3: Physiotherapists use different reference points to measure the range of movements through Goniometer. Some examples of reference axis include using: (a) the flat surface, (b) a point on the heel, and (c) a point under the ankle joint.

point of reference for measuring the range of movement, the comparison of values will also be accurate. Finally, to clearly highlight the point of reference and the angular displacement for the range of movement, I developed the side view of foot sketches, as shown in Figure 7-4b. Secondly, the information related to foot orientation was removed,



(a) (b)

Figure 7-4: Revision of the *SoPhy* visualisation: (a) The earlier design presented the range of movement data in numbers, (b) The revised design presents the range of movement as angular displacement.

as it can be inferred partly from the visualisation of weight distribution and partly from the range of movement visualisation. As found in Study 2, lateral and medial orientations are associated with weight bearing patterns and participants retrieved this information directly from the weight distribution visualisation. Additionally, the collaborating physiotherapist pointed out that the other two orientations, i.e., plantarflexion and dorsiflexion, are related to the range of foot movement, which is already covered by the range of movement visualisation. Finally, the revised web-interface presents visualisation related to weight distribution and range of movement, as shown in Figure 7-4b.

Spatial Alignment between Visualisation and Video Stream

To fulfill this design goal, SoPhy web-interface went through two changes. The first change was related to the order of the patient's foot listed on the visualisation, which confused the participants in Study 2. One option to overcome the confusion was to split the visualisation per foot and to overlay the visualisation on either side of the video, such that information related to each foot is presented alongside the patient's foot. Figure 7-5 presents the paper prototype that was used in the meeting for the discussion. However, the idea was discarded following the suggestion of the physiotherapist, as splitting foot would not support the comparison of both feet. He described that both feet should be together, as the absolute values of these sensors are not meaningful without it. Rather it is the comparison of the values that would highlight the difference in the patient's foot movements. Therefore, I switched the order of foot to left and right for both visualisations to resolve the confusion around mapping. Consequently, I changed the orientation of foot sketches from feet facing inside (refer upper part of the Figure 7-4a) to feet facing outside (refer right part of the Figure 7-4b), as this arrangement allowed easy comparison of the range of movement for both feet.

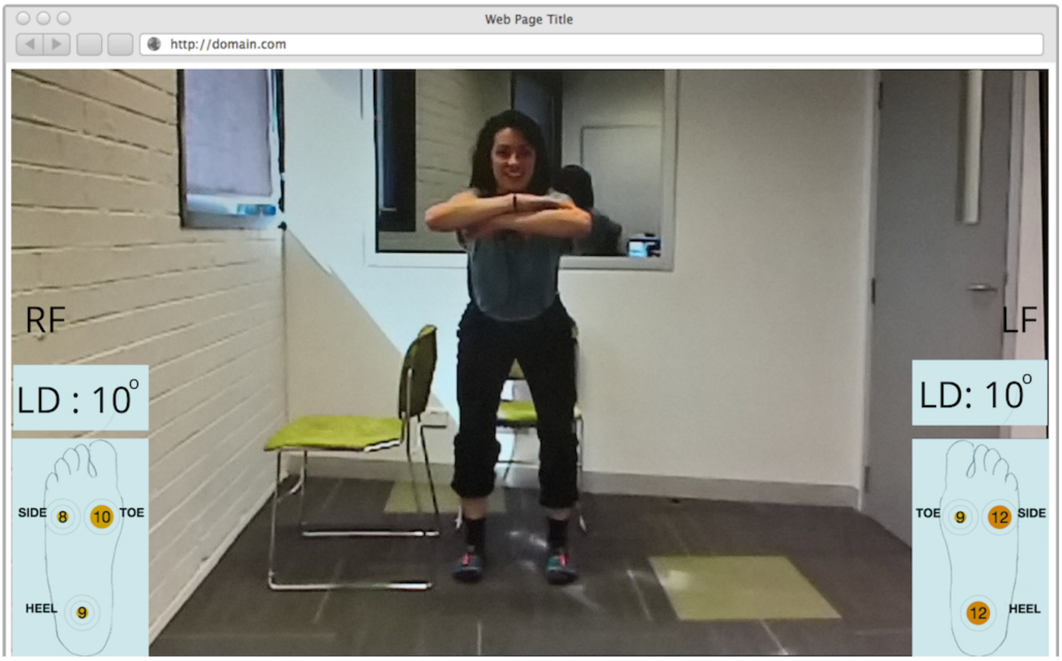


Figure 7-5: One possible way of visualising the data was to overlay the information on the video stream. This paper prototype was discussed in the meeting with the physiotherapist.

Improving the Readability of Visualisation

Finally, some changes in the interface were made to improve the readability of the visualisation in real-time. In this regard, information related to weight distribution went through one revision, which included removal of the sensor values on the circles. The numbers were found difficult to read in real-time in Study 2. Hence, the revised visualisation of the weight distribution only included a continuous color spectrum (left part of the Figure 7-4b). Additionally, to reduce the amount of information on the web-interface, the foot sketches for the range of movement only contained the foot outline (refer right part of the Figure 7-4b) and not any details of the foot (refer upper part of the Figure 7-4a).

7.3.3. Revised List of Bodily Information Captured by SoPhy

Below I describe the revised set of lower body information related to weight distribution, foot orientation and range of movement, as presented on the *SoPhy* web-interface.

Weight Distribution

Weight distribution describes the amount of weight a person is bearing at different points on the sole of the foot. *SoPhy* captures the weight bearing pattern through the pressure sensors sewed on the socks at three locations – at the balls and heel of the foot. On the web-interface, weight distribution is presented using a sketch of the underside of the foot. Each sensor point is presented by three concentric circles, where each circle represents a category of weight distribution. Overall, the weight distribution is presented across three categories of Low (0-9), Medium (10-19) and High (20-30), extended across a continuous color spectrum from light yellow to dark on a scale of 0-30, where the numbers represent the pressure sensor values (see the left part of the Figure 7-4b).

Foot Orientation

Foot orientation describes the foot alignment in the following four directions: (1) Dorsiflexion occurs when toes point up towards the head, (2) Plantarflexion is when toes point downwards away from the leg, (3) Medial orientation happens when the outside part of foot is up in the air; and (4) Lateral orientation occurs when the inside part of the foot is up in the air (refer to Section 5.4 for more details). Medial and lateral foot orientations are respectively related to the weight bearing pattern inside and outside of the foot. This information is inferred from the weight distribution visualisation on the web-interface. On the other hand, dorsiflexion and plantarflexion are respectively related to the foot extending towards the head and the foot pointing downwards away from the head. This information is presented by the visualisation of range of movement.

Range of Movement

Range of movement refers to the angular displacement of foot in dorsiflexion and plantarflexion position. The angle is calculated from the point under the ankle joint, as shown in Figure 7-3c. The angle is calculated by the IMU sensor. (The reference axis of the IMU sensor is parallel to the axis on the ankle point, and hence the corresponding angles are equal.) On the web-interface, foot range is presented using foot sketches from the side view (refer right part of the Figure 7-4b). Mimicking the foot movements, these foot sketches move up and down in between the maximum degrees of dorsiflexion (30 degrees) and plantarflexion (50 degrees), defined for a healthy person (Attridge, 2008). The angular displacement of the foot is represented using a wedge visualisation, which is inspired by the work of Tang and colleagues (Tang et al., 2015).

7.4. Methodology

The aim of this study was to understand how does *SoPhy* contribute to the overall efficacy of physiotherapists in assessing and treating patients with lower limb issues when video consultations are organised in the hospital setting. Following field deployments methodology, the study was conducted in the same research context with same physiotherapists as was the case in Study 1, i.e., at the Department of Anaesthesia and Pain Management, Royal Children's Hospital, Melbourne. Having the same research context was essential here because *SoPhy* was designed by considering the clinical practice of the physiotherapists at the hospital. Additionally, I established a good relationship with the department and the physiotherapists particularly with one physiotherapist (pseudonym: Phil) who was actively involved across all phases of this research including the design and laboratory evaluation of *SoPhy*. His participation in this study helped me in getting the ethics approval at the hospital as well as in recruiting the patients. Below I describe the activities and methods followed to conduct field deployments of *SoPhy*.

7.4.1. Pre-study Activities

Commencing field deployments of a prototype system involved significant efforts in terms of getting ethics approval, validating the study design and developing the system for the study. I briefly describe each of the activities below.

Ethics Approval

Evaluating *SoPhy* at the hospital required ethics approval from the hospital ethics committee. The ethics application went through a rigorous process with different departments approving the intervention of *SoPhy* in the clinical practice, overall taking three months for approval. The lengthy and stringent process ensured that *SoPhy* is suitable to be put on the patients and that it can be successfully used by the physiotherapists for their clients. For instance, because the study was focused at evaluating a new device in the clinical setting, the application went through the device sub-committee to ensure that the new device does not create any issue for the patients. Additionally, as patients are required to wear the *SoPhy* socks, the application sought approval from the hygiene committee. Furthermore, the application required approval from multiple higher authorities at different levels at the hospital, including the head of the collaborating department, research coordinator of the hospital, telehealth coordinator, and the IT department. For faster outcome, approval from multiple people was sought in parallel. At each department level, the application went through multiple revisions to confirm that the study design fulfills the hospital protocol and that it does not expose patients to any new risks. Finally, the application was reviewed by the hospital ethics committee, and *SoPhy* was successfully approved to be used with patients having lower limb issues.

Pilot Sessions

After getting the ethics approval, I organised two pilot sessions with Phil and one with Peter. These sessions lasted for 40-60 minutes and offered multiple insights. These pilot sessions were conducted to demonstrate them the working of *SoPhy*, e.g., what part of the *SoPhy* web-interface presents which bodily information, how to use *SoPhy* in addition to the screen running video call, and what are the study tasks for clinicians and patients. Besides these goals, the sessions with Phil were more interactive and required his significant involvement to take multiple decisions about the study protocol. I conducted role-playing with Phil where we organised video consultations across two rooms at the hospital. Mimicking a patient, I wore the *SoPhy* socks and performed certain movements, and Phil used the *SoPhy* web-interface to look at the movement data. This role-playing helped me to figure out both technical and administrative activities related to conducting the study. For instance, it gave insights into how to arrange the *SoPhy* web-interface in the room, how to setup the server connection of *SoPhy* to support data between the sock data and server, and how to access the hospital Wireless connection. On the other hand, these sessions gave insights into which consultation rooms were best for the study, how to book these rooms for the study, and how to get access to the consultation rooms prior to the study sessions. For instance, I selected those rooms where no rearrangement was required prior to the session and where the lighting was good for the video consultations. After these pilot sessions, I developed a checklist of the tasks to be done before, during and after the study in order to prepare myself for the study session.

Preparing SoPhy

I developed two large and one small sized pair of *SoPhy* socks to prepare for a range of foot sizes before commencing the study. However, all three patients who participated in the study were tall (around 5 feet 8 inches), hence, only large-sized pairs were needed. Although the socks were developed beforehand, they required regular management throughout the study. Because the electronics on each sock faced some issues after a couple of use, e.g., often the pressure sensor(s) generated incorrect readings, which required replacing the pressure sensors or altering the Arduino pin connection. To tackle these issues, I also developed additional pairs of socks for use during the course of study. As such, being a prototype system, *SoPhy* required consistent management throughout the study. *SoPhy* also went through certain changes during the study period to make it work smoothly, for instance, the mobile app was modified to directly input the IP address of the hospital location to save time in setting up *SoPhy* before consultations. All these changes were inspired by the technical issues that I faced either in setting up the system or during the session. These changes were done by following the guidelines of Siek and colleagues (Siek et al., 2014) - they suggested that the technology should be appropriately managed during deployments to save time and resources of the participants.

7.4.2. Study Design

The design of the study was informed by the sensitivity of the clinical setting and the ethics guidelines at the hospital. As such, conducting field deployments of *SoPhy* was challenging. Several decisions were taken that deflected from the study aims but were essential to be able to conduct this study as well as to be in alliance with the hospital protocol. Firstly, 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. The 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 for conducting observations. Additionally, as the technology was new for participants, mailing the *SoPhy* socks to patient's address was also not appropriate. The socks were not ready for unsupervised use and required technical support to support its use in a session. Consequently, I simulated the setting of video consultations across two rooms at the hospital, which allowed me to gain a detailed understanding of the interactions of both patients and physiotherapists with *SoPhy* through observations and interviews.

Finally, although the study aimed at understanding the use of *SoPhy* in video consultations, I also conducted field deployments of *SoPhy* in face-to-face consultations. This decision was motivated 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 or at the start of the video consultation was not considered feasible by the hospital staff because the chronic pain patients follow a complex condition. Hence, the study was designed such that all patients used *SoPhy* first in a face-to-face consultation and then in a video consultation. In this regard, the study design involved observations of at least two sessions with each physiotherapist-patient pair. A summary of the study design is provided in Figure 7-6. All subsequent sessions were required to follow the structure of the second session. Below I will discuss the details of these sessions.

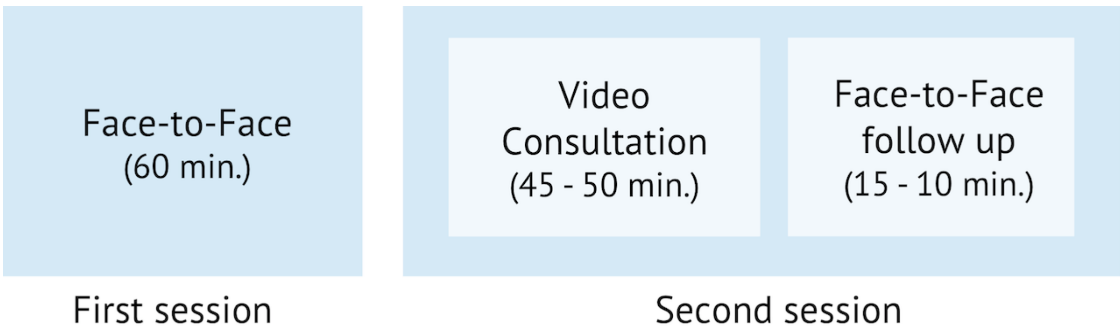


Figure 7-6: The first session with *SoPhy* was a face-to-face consultation. The second session was a video consultation followed by a short face-to-face follow up. All consultations were organised at the hospital.

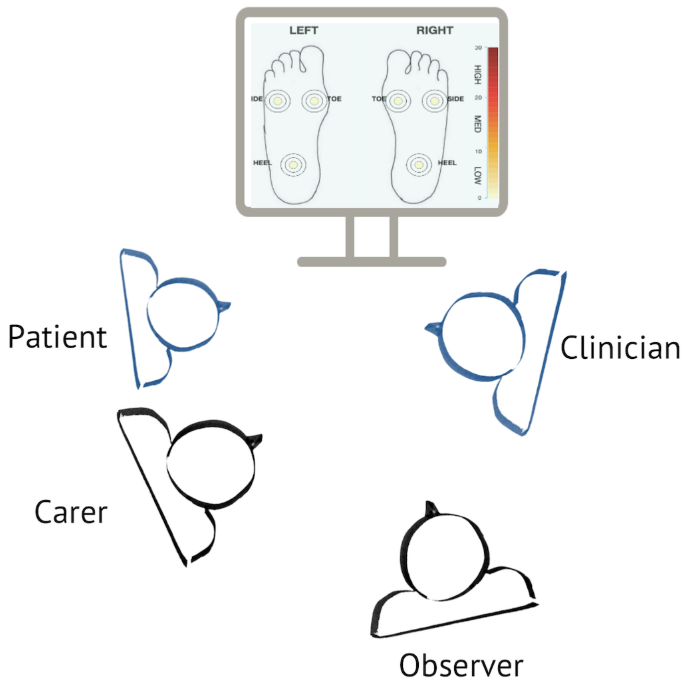


Figure 7-7: Each patient-physiotherapist pair was introduced to *SoPhy* in a face-to-face consultation. I was present in the session to collect data.

Session 1: SoPhy in Face-to-Face Consultation

The aim of this session was to introduce *SoPhy* to the patient and physiotherapist pair, to allow them to explore the use of the system for the patient's condition (refer Figure 7-7). During the consultation, patients were required to wear the *SoPhy* socks before continuing with the consultation. For hygiene purpose, the patients wore the *SoPhy* socks on top of their own socks, or on top of thin stockings that I provided. On the other hand, tasks for physiotherapists included using the *SoPhy* web-interface during the session to read the movement related data of the patient. The *SoPhy* screen was placed in a corner of the room to provide sufficient room to the patient and physiotherapist for performing different exercises. I was present in the room to conduct passive observations and to offer technical support for using *SoPhy*.

Session 2a: SoPhy in a Video Consultation

The aim of this 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, which was followed by a short face-to-face follow up. This structure of the session was inspired by an earlier study conducted at the Royal Children's hospital, where the research team evaluated the technical setup of video consultations for surgery related consultations (Stevenson, 2011). Following Stevenson's study, a short face-to-face catch up was organised after the video consultation to allow patients to

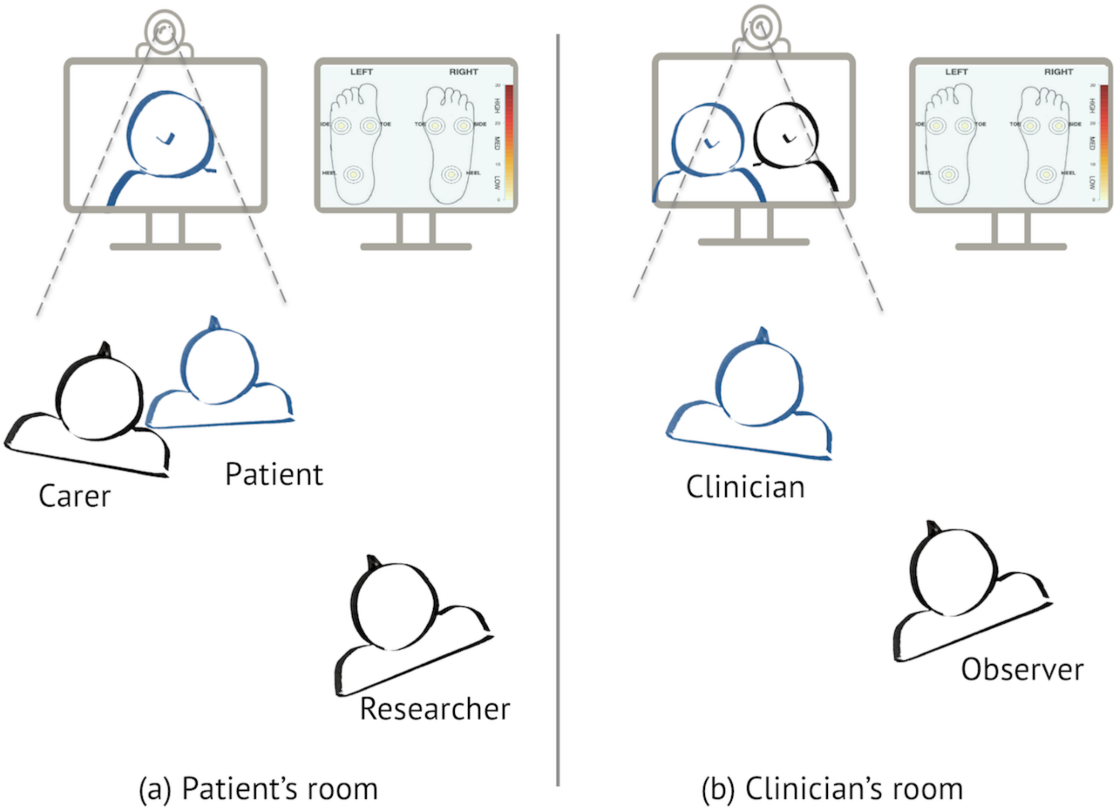


Figure 7-8: Video consultations were arranged across two rooms in the hospital. The patient was accompanied by another researcher to provide the technical assistant, whereas I was present with the physiotherapist to collect data.

meet their physiotherapist in person and to discuss any outstanding issues that they could not raise in video consultations. Allowing this face-to-face interaction was important because, for the majority of the patients, each physical trip involved dropping the school for a day and a commute time of a couple of hours. It would have been unfair for the patients to not able to meet their clinicians when they were already at the hospital. Another important point to note here is that this face-to-face follow up was organised only in the end and not in the beginning to keep the setting of video consultation natural. This structure ensured that the video session follows all six phases of a consultation – opening, history taking, examination, diagnosis, treatment, and closing (as described in Section 2.2.1). If the face-to-face meetings were held in the beginning, physiotherapists would have already formulated their initial assessment by seeing the patient in person, and those insights would have naturally made video consultations more effective.

For the video consultation, the patient and physiotherapist were in different rooms at the hospital and met each other over the video call. Figure 7-8 shows the setup of the rooms. In both rooms, two screens were arranged - one for the video call and another for the *SoPhy* web-interface. *SoPhy* web-interface was also presented to the patient to support conversations around the visualisation. Also, these screens were arranged in the same way in both the rooms to avoid any confusion in referring to the visualisation. Additionally, considering the design consideration from Study 1 on '*Extend the time sequence of video consultations*' (Section 4.6), I started the *SoPhy* web-interface 5-10 minutes before starting the video call. This was done to extend the opening of the video consultation so that the physiotherapists could observe incidental movements of the patients right from the beginning of the consultation. During video consultations, I was present at the clinician end to conduct observations, whereas another researcher (Dr Thuong Hoang) was present at the patient side to provide technical support whenever needed. Tasks for the patients included wearing the *SoPhy* socks on top of their socks or stockings and continuing with the consultation. On the other hand, physiotherapists were encouraged to refer to the *SoPhy* web-interface to read the patient's movement related data.

Session 2b: Face-to-face Follow up

The video consultation was followed by a short face-to-face catch up, where the physiotherapist came over to the patient's room to discuss any unresolved issues that were not discussed during the video consultation. These follow-ups followed an open structure without any prescribed activities for patients and physiotherapists. This phase was designed to provide an opportunity to the patients and physiotherapists to meet in-person so that the patients who had traveled to the hospital for a face-to-face consultation did not have any outstanding issue before leaving the hospital site. I conducted observations of this session as well, to understand the activities performed by physiotherapists and patients in this session, and to distinguish what activities were not possible in video consultations.

7.4.3. Participants

The study was conducted in collaboration with the same two physiotherapists (Pseudonym: Phil and Peter) from the Royal Children's Hospital, who participated in Study 1. The study continued for a period of five months, where the collaborating physiotherapists recruited patients with lower limb issues to participate in the study. The physiotherapists were provided with a script to help them explain the project to their clients (refer Appendix D.2 to check the clinician's script). Three patients and one physiotherapist (Phil) participated in the study. The low number of participants is understandable given that the patients were selected based on the following recruitment criteria. Firstly, patients with lower limb issues were invited to participate. Lower limb rehabilitation is one of the several conditions for which the collaborating department offers treatment. And there is no fixed number of patients who will visit the hospital at a particular time. Secondly, not all patients with lower limb issues could participate in the study. As the department deals with patients having a chronic condition, some of the patients are vulnerable and have a complex condition, which restricts them from trying out a new wearable technology. Furthermore, some potential patients did not agree to have video consultations with their physiotherapist. The reason being that these patients were making a physical trip to the hospital, which required them to skip their school and long hours of drive. Because of these efforts, they were willing to meet their physiotherapist only in a face-to-face setting.

Consequently, I recruited three patients who were available at the time of the study. These patients were clients of Phil, whereas Peter did not have any clients with lower limb issues during the study period. I conducted observations of six naturally occurring consultations that were organised by Phil for three patients - Sally, Paige, and Erica (pseudonyms). These patients aged between 11-17 years at the time of the study. I hold an approved *Working with Children Check* in addition to the hospital ethics to conduct research with young children. Table 7-2 provides a list of the sessions observed with each patient along with details on their health status at the beginning of the study. Besides the patient and physiotherapist, these consultations also involved other people such as the patient's mother, occupational therapist, and psychologist, at different times.

Patients	Session No.	Session Type	Time Since Previous Session	Other Attendees
Sally	*__Condition__: Weight bearing issue in left leg; Experience high pain in both feet; Highly anxious to bear weight on left foot			
	1	Face-to-face	--	Mother
	2	Video	1-week	Mother
Paige	*__Condition__: Use crutches to walk; Weight bearing issue in left leg; Experience high pain in left leg; Highly anxious to bear weight on left foot			
	3	Face-to-face	--	Mother
	4	Video	1-week	Mother
	5	Face-to-face	3-months	Mother, Psychologist, Occupational Therapist
Erica	*__Condition__: Use crutches to walk; Weight bearing issue in right leg; Experience high pain in right foot; Highly anxious to bear weight on right foot			
	6	Face-to-face	--	Mother

Table 7-2: Details of the sessions observed with three patients and one physiotherapist. (*Condition describes the patient's health status at the beginning of the study.)

All patients had different chronic conditions associated with lower limb ranging from localised foot injuries to leg injuries to knee injuries. As explained by the physiotherapist, the first patient, Sally was diagnosed with Complex Regional Pain Syndrome (CRPS) in her right leg. She sprained her left ankle a couple of months back and had injured her left knee. She had high pain in both feet and was very anxious when doing any activity. She had bearing weight issues in her left leg. The second patient, Paige had undergone a clinical procedure on nerve block in her left knee, where the nerves that were causing pain in her left leg were made numb with medication. She was using crutches to walk. She was in high pain and had weight bearing issues in her left leg. She was also very anxious and fearful of putting weight on her left foot. Finally, the last patient, Erica had chronic pain in the bone under the big toe of her right foot, the condition referred to as Sesamoiditis. She had high pain and high anxiety of bearing weight in her right foot, and she was using crutches to walk.

One commonality across all patients was that they all were struggling to having a normalised weight bearing pattern. Normalising weight bearing is one aspect of lower limb rehabilitation, where the aim of physiotherapists 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. Normalised weight bearing is only one of the many phases of physical rehabilitation. For instance, rehabilitation starts with body awareness, which aims to optimise the patients' sensorial capacity through meditation. The next step is to improve the patient's balance, where the patient practises some movements while lying down on a bed and then sitting on a chair. The next goal is having the normalised weight bearing pattern, which then progresses to improving patient's flexibility, endurance and strength until they reach their goal. These goals are formulated by the patients and may vary for different patients.

Finally, the study design also changed because of the different conditions of the patients at different times. Also, although the focus of this study was on physiotherapists, the involvement of other clinicians influenced the scheduling of consultations. For instance, following the study design, I conducted one face-to-face and one video consultation with Sally and Paige. However, I also conducted an additional face-to-face session with Paige (session 5), which was organised after three months of her video consultation. This session was organised as a face-to-face consultation and not as a video consultation because the session required the involvement of multiple clinicians like an occupational therapist and psychologist, which clinicians found challenging to pursue over video. This issue resonates with the challenge C2 observed in Study 1 (Section 4.5), where it was difficult to involve multiple clinicians in video consultations and the video consultation mainly involved the physiotherapist for the entire session. Since Phil was interested to assess her improvement through *SoPhy*, therefore, face-to-face was organised. Moreover, I 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.

7.4.4. Data Collection

The data collection for the study was guided by the four aspects of the efficacy model: *Diagnostic accuracy efficacy, Diagnostic thinking efficacy, Therapeutic efficacy* and *Patient outcome efficacy* (the efficacy model is described in Section 2.2.4). Table 7-3 presents the parameters utilised in the study for the data collection. These four aspects helped me to investigate the utility of *SoPhy* for both patients and physiotherapists. For this study, I also evaluated the influence of *SoPhy* on the patient because the diagnosis and treatment of the clinicians are successful only if the patient provides complete information on their health condition and is able to successfully follow the recommended therapy (Demiris et al., 2010). While the first three aspects guided the data collection from physiotherapists, the last aspect of the *Patient outcome efficacy* helped me to

#	Aspects of the efficacy model	Parameters corresponding to each aspect (Relevant to this study)
1	Technical efficacy	Not the aim of this study
2	Diagnostic accuracy efficacy	a. Instances of corrections in the assessment
3	Diagnostic thinking efficacy	a. Understanding of the patient's health issue b. Influence on confidence in assessing the patient c. Ability to assess different exercises
4	Therapeutic efficacy	a. Change in treatment choices b. Influence on the clinician-patient communication pattern c. Ability to try out exercises with patients
5	Patient outcome efficacy	a. Ability to describe symptoms b. Understanding of own health issue c. Ability to try out different exercises

Table 7-3: Data collection was guided by four aspects of the efficacy model described in Section 2.2.4.

investigate the use of *SoPhy* for patients. On the other hand, the technical efficacy of the model was not relevant in this study because the laboratory evaluation of *SoPhy* (Study 2) already confirmed its technical efficacy to support lower limb assessment (refer Chapter 6 for more details). Although being a research prototype, *SoPhy* was expected to have certain technical issues like Bluetooth disconnection and delay in data rendering.

I also want to make a note that the data collection started with the aim of understanding how *SoPhy* helps physiotherapists in assessing and treating patients during video consultations. The focus on efficacy was defined over time, as my understanding of how *SoPhy* was supporting both patients and physiotherapists emerged, which I will explain in the data analysis. In order to refine the study goals, I conducted the data analysis simultaneously with the data collection. However, for clarity and ease of reading, I will separately describe the data collection and analysis.

I used three methods to collect data from the field, which included participant observations and informal conversations and semi-structured interviews. Besides, photographs of the room and the patients (focusing on the foot and *SoPhy* socks) were taken to record the use of *SoPhy* during the session. These methods were specifically chosen to keep the setting natural and comforting for patients who were under 18 years. Also, I did not make the screen recording of the *SoPhy* web-interface, as the data in itself was not sufficient to describe the activities of the patients, i.e., from the screen recording, it was difficult to find out what data corresponds to which exercise. Consequently, field notes became the main source of data collection during the session and interviews for post-session. Below I will describe all the methods employed in this study for data collection.

Participant Observations

I conducted participant observations (Emerson et al., 2011) to understand how *SoPhy* supported physiotherapists for different patient's conditions, and what kinds of interactions happen with and around *SoPhy*. In total, I conducted observations of two video consultations and four face-to-face consultations with *SoPhy* (as listed in Table 7-2). Observations of video consultations were conducted from the clinician's location because the study was focused on understanding the influence of *SoPhy* in supporting physiotherapist's assessment and treatment process. On the other hand, during face-to-face consultations, I was present in the same room with patients and physiotherapists to conduct observations. (Appendix D.3 presents the observation guide used for the data collection.)

During the consultation, I took shorthand notes to quickly capture the events of the session. I followed the same process of notes taking as I used in Study 1. In this regard, all the notes were manually taken in a notebook. These notes included texts to capture the conversations between participants, and sketches to record the arrangement of the room and participants as well as to record activities involving bodily information such as the patient's exercise patterns. Sketches were significantly helpful in recording the visualisation screen, as there was no other means to record the screen. For instance, to record the visualisation of weight distribution for a certain exercise, I noted down the circle size and approximate color from the continuous color spectrum. Similarly, for recording the range of movement for a given exercise, I sketched the angles in my notebook. This way of recording the visualisation was not very accurate, as there were errors in recording the exact colors of the pressure sensors. However, it was the best way to collect data non-intrusively. Capturing visualisation was important as it provided context to the conversations of the participants, and informed what information of the visualisation was useful for physiotherapists and patients and for what purposes. (Appendix D.4 shows examples of the field notes taken during the session.)

During the session, I also noted down parts of the session that was not clear to me or that required further explanation from the physiotherapist, e.g., why was the visualisation important for a specific movement of the patient or what was the reason behind setting up a goal around the visualisation for the patient. These notes were then used during the interview. Additionally, I also checked my interview guide to prepare questions that were more relevant to ask the physiotherapist for the ongoing session. In this regard, I added more questions or ticked off some questions from the list.

Immediately after the session, I sat in a quiet location to develop detailed field notes related to the session. The shorthand notes taken during the session jogged my visual memory and I was able to recall the events. The detailed notes were again developed on a notebook because of the ease to write and draw sketches on a notebook than a computer. I used different color pens to highlight the important events of the session. As I was writing, I also coded the data with pencil mark-ups. Appendix D.4 shows how I combined coding with transcribing the field-notes. Along with the detailed notes, I also developed a summary of the key highlights from the session. This summary was my reflection on how the session went and how was it different from the previous session. These reflections were supported by the points discussed during the informal conversations or interviews with the physiotherapist. These detailed notes became the starting point for the data analysis.

Informal Conversations

Apart from conducting observations, I also capitalized on every opportunity to have informal chats with the physiotherapist to reflect upon the latest event in a think-aloud manner. These conversations lasted for a few minutes and were noted down as field-notes. These conversations were elaborated in the similar manner as that of the field-notes. I initiated these conversations while the physiotherapist was setting up for the consultation, and when there were technical issues during the video consultations.

For instance, before beginning the consultation, when Phil was reading through his notes from the previous session to remind himself about the patient's condition, I asked questions about the patient's history. I tried to best utilise the time before the beginning of the session, as it helped me to understand the patient's condition as well as to clear some points that carried over from the previous session with the same patient. Because of the time limitation, often I could not finish some conversations. I tagged these conversations to revisit them post-session during the interview to get a deeper reflection on certain events.

Similarly, I had informal chat with the patients when they were wearing the socks, or during technical issues with *SoPhy*. Such conversations were only possible during face-to-face consultations as I was present in the same room with the patient and physiotherapist. However, during video consultations, informal conversations were not conducted with the patients as I was present with the physiotherapist in another room.

Interviews

After the consultation, semi-structured interviews were conducted with the physiotherapist and patients to understand their overall experience with *SoPhy*. In total, eight interviews were conducted with Phil - (1) one after each the session to understand the use of *SoPhy* in the session (six interviews), (2) one in the middle of the study to reflect upon the use of *SoPhy*, and finally (3) one at the end of the study to reflect upon the overall use of *SoPhy* for all the patients. These interviews lasted for 40-90 minutes. The interviews were guided by the interview guide as well as by the notes taken during the session (refer Appendix D.5 for the detailed interview guide). Having the opportunity to interview the physiotherapist after each consultation was significantly helpful to get a detailed understanding of the use of *SoPhy* for each patient at different times. For example, the physiotherapist compared the use of *SoPhy* for the patient in the session with previous consultations when *SoPhy* was used as well as when *SoPhy* was not used - to highlight the influence of *SoPhy* for a patient at different times. Additionally, since the study was conducted with the same physiotherapist who participated in Study 1, I was able to ask questions to compare the sessions with Study 1.

Conducting interviews with the patients was difficult because these patients had consequent consultations with other clinicians. However, I managed to conduct two semi-structured interviews, one each with Sally and Paige after their last session with *SoPhy*, i.e., after sessions 2 & 5 respectively (refer Appendix D.5 to check the interview guide used with the patients.) Interviews with the patients were conducted in presence of their carer and lasted for around 20 minutes. All the interviews were conducted at the hospital and were audio-recorded for later analysis.

Immediately after the session, I made a summary of these interviews in my field notes diary. This summary became a part of the session highlights that I wrote after each session. Since there was sufficient time between two study sessions, I transcribed the interviews in between these sessions. The interviews were manually transcribed on a computer using Express Scribe Transcription software to get the exact quotations of the participants. Manual transcription of these interviews helped me to get immersed in the data and to have ongoing reflection on the overall data collection. I started coding the data as I was transcribing, where I gave topic sentences to different parts of the interview based upon their relevance. Appendix D.6 shows a snapshot of the coded interviews.

7.4.5. Data Analysis

The analysis was aimed at developing a detailed understanding of how *SoPhy* helped physiotherapists in assessing and treating patients during video consultations. I employed thematic analysis approach (Braun and Clarke, 2006) to analyse the data generated from the field work, which included: (1) Six scripts of the detailed field notes developed from the observations of video and face-to-face consultations with *SoPhy,* (2) Six scripts of the session highlights containing my reflection on the session and key points from the interviews and informal conversations, and finally (3) Ten audio recordings of the interviews conducted with the physiotherapist and patients.

The data was analysed iteratively using both inductive and deductive approach. While the inductive analysis allowed new themes to emerge from the data, deductive analysis helped me to confirm the findings of Study 1 and Study 2 in order to bring this thesis to closure. For instance, having conducted the other two studies, the deductive analysis was guided by the challenges found in Study 1 and the benefits of *SoPhy* revealed in Study 2. Additionally, the analysis was also guided by the six phases of clinical consultations that were used in Study 1 to describe the activities between patients and physiotherapists. Besides, the emerging trends and themes generated across sessions were regularly discussed with my supervisors to reflect upon the data. Additionally, using Member Checking (Cho and Trent, 2006), the themes and sub-themes were also discussed with the collaborating physiotherapist to validate my interpretation of the data. Below I describe how the themes and sub-themes were generated iteratively.

Coding the Data

Getting familiar with the data and coding the data were an ongoing process throughout the study. Coding started from the beginning of the data collection, where I started reflecting on each study session immediately after the session. After each session, I read the observation notes and the session highlights from the field notes diary and coded the data with pencil mark-ups. This analysis was driven by the findings of Study 1, for instance, I analysed how *SoPhy* was used in different phases of a consultation, and whether and how *SoPhy* resolved any challenges found in Study 1. To support this comparison between this study and Study 1, I developed two tables - one comparing the findings with the challenges of Study 1 and another comparing the bodily information available across different phases of the consultation. Appendix D.6 shows the tables generated after four sessions of the study. While I was making comparison with Study 1, I was also checking if the data also confirm the findings of Study 2 related to the benefits of *SoPhy* in assessing patients (e.g., increased diagnostic confidence of physiotherapists and reduction in number of exercise repetitions). This comparison helped me to continuously reflect on the collected data and the data collection methods. Depending upon this reflection, I revised the interview guide and observation guide to specifically look for certain activities that I felt were essential to understand the utility of *SoPhy*.

However, analysing the data deductively through the findings of Study 1 was not sufficient. The study revealed new insights of the benefits of *SoPhy* for both physiotherapists and patients that I did not anticipate. *SoPhy* being a new technology created venues for new interactions and activities. For instance, after conducting two sessions with the first patient, the study highlighted the potential of *SoPhy* for the treatment as well. The visualisation proved helpful for the patients to understand their progress as well as to set new rehabilitation goals. Since diagnosis and treatment are interlinked with one affecting the other, I needed another lens that could help me to illustrate the benefits of *SoPhy* throughout the consultation for both patients and physiotherapists. The six phases of consultations were also not sufficient because it only offered a structure to describe different the activities throughout a consultation. However, what I needed was a theory or a concept that could guide me to evaluate whether and how *SoPhy* was making video consultations more effective than the standard video consultations practice.

I returned to the existing literature to understand ways to investigate a technology in clinical setting. I was looking for a concept that could be used in the qualitative inquiry to collect rich data from the field as well as to achieve rigour in the data collection. Rigour in the data collection was also essential because I expected to conduct this study only with a few patients, as participation in the study involved a specific recruitment criterion (as discussed in Section 7.4.1). I came across to the efficacy model (Fryback and Thornbury, 1991) that aims to investigate the efficacy of a new technology in clinical context. The model has different parameters to investigate how a new technology supports clinicians in performing their clinical tasks such as assessment and treatment (refer to Table 2-2 in Section 2.2.5 for more details). I focused on the four aspects of the efficacy model to collect data as it aligned well with the study goals of understanding the influence of *SoPhy* on physiotherapists in assessing and treating patients. These aspects included *diagnostic accuracy efficacy, diagnostic thinking efficacy*, *therapeutic efficacy* and *patient outcome efficac*y, as listed in Table 7-3. The benefit of using this model was that it overlapped with the six phases of the consultations that I intended to use to structure the study findings. Additionally, the parameters related to the *diagnostic* *thinking efficacy* and *diagnostic accuracy efficacy* (e.g., confidence and exercise repetition) also served pointers to the Study 2 findings. Hence, addressing the parameters of the efficacy model in turn, confirmed the findings of Study 2. To this end, having the model did not made the data collection confusing, rather it became a lens to conduct an in-depth inquiry on the activities of participants for each phase.

After adopting the efficacy model, the study aims were refined. Similarly, the interview guide was revised to collect data around different parameters of the model. Appendix D.5 shows the interview guide that was developed after the introduction of the efficacy model. Although I adopted the efficacy model, I continuously compared the study findings with Study 1 because it was allowing deeper reflection on the data. To this end, for each consultation, I analysed the data around the efficacy model, challenges found in Study 1 and bodily communication in six phases of clinical consultations. Finally, another part of the coding happened after finishing the data collection with six patients, when all the collected data was repeatedly read to generate codes. During this time, I coded the transcribed interviews on the printed copies to get the exact codes of the participants to support the findings. Appendix D.7 presents how the transcribed interviews were coded on paper.

Defining Themes and Sub-themes

Following the structure of Study 1, the main themes of this study were defined from the beginning of the study, which included Opening, History Taking, Examination & Diagnosis, Treatment and Closing. Having the same structure helped me to highlight the differences in the interactions and activities of the participants in both studies. Additionally, I utilised the same vocabulary of bodily information that I used in Study 1 to get consistency in the findings (the vocabulary is listed in Table 2-4 in Chapter 2). On the other hand, defining sub-themes started along with the coding of data. Because I was comparing the study findings with the challenges found in Study 1, the sub-themes were framed to highlight how *SoPhy* resolved the given challenge in each phase (as listed in Appendix D.6). However, these sub-themes were iteratively refined and new sub-themes were added along the way to describe the use of *SoPhy.* Because themes and sub-themes were intertwined with coding, the field notes and interview transcripts in different iterations were not only coded with new codes but also with the relevant themes and sub-themes. Appendix D.7 presents how the transcribed interviews were coded with the relevant sub-themes number from the comparison described in Appendix A.6.

Once the data collection phase was completed, I followed deductive approach to analyse the generated themes and sub-themes. The analysis was again guided by the efficacy model, bodily communication around different phases of consultations and the challenges faced in Study 1. However, to illustrate the influence of *SoPhy* on the practise of physiotherapists, I decided not to compare the study findings with Study 1 challenges in the Findings section. Rather the comparison became a part of the Discussion section. On the other hand, the comparison of bodily information was removed as comparing bodily information in two different studies was misleading. For instance, some bodily cues varied because of different patients who had different attitudes and different health conditions. Additionally, some bodily cues emerged because of the presence of *SoPhy*, e.g., hand gestures to *SoPhy* interface. Whereas, some bodily cues like eye contact was used throughout the session but were not listed because they were not relevant for the specific events described in the findings.

Later, the sub-themes were structured around the five main themes related to the phases of the consultations. 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. Findings were iteratively revised to answer the four aspects of the efficacy model, i.e., Diagnostic accuracy efficacy, Diagnostic thinking efficacy, Therapeutic efficacy and Patient outcome efficacy. Apart from the benefits of *SoPhy* for patients and physiotherapists, the study also highlighted certain technical issues with the use of *SoPhy.* I listed these issues under a separate theme on '*Technical issues in using SoPhy*'.

The outcome of this analysis is presented across six themes in the next section, namely Opening, History Taking, Examination and Diagnosis, Treatment, Ending and Technical Issues with *SoPhy*. To present the study findings, I have utilised insights from both face-to-face and video consultations because *SoPhy* proved equally beneficial in face-to-face setting as it was in video consultations. The insights from face-to-face settings in fact make a stronger case of the potential of *SoPhy* in video consultations because *SoPhy* proved beneficial even in the traditional consultations that are considered as most effective. The use of *SoPhy* in face-to-face consultations also highlighted certain interactions with *SoPhy* that were not observed in video consultations. These interactions are listed under 'Technical Issues with SoPhy'.

7.5. Findings

Following the same structure as Study 1, below I structure the findings across six phases of a clinical consultation. Findings are enumerated around the names of the phases, e.g., findings on the opening phase are listed as O1, O2. Similarly, findings for History taking phase are listed as H1, H2. Within each finding, I have narrated instances from both face-to-face and video consultations to illustrate the use of *SoPhy*. Figure 7-9 shows the mapping between the study findings across six phases and different parameters of the efficacy model. This mapping is based on the mapping presented in Section 2.2.5 (refer to Table 2-2). Besides, the technical issues with *SoPhy* are discussed separately under the heading 'Technical issues in using *SoPhy*'.

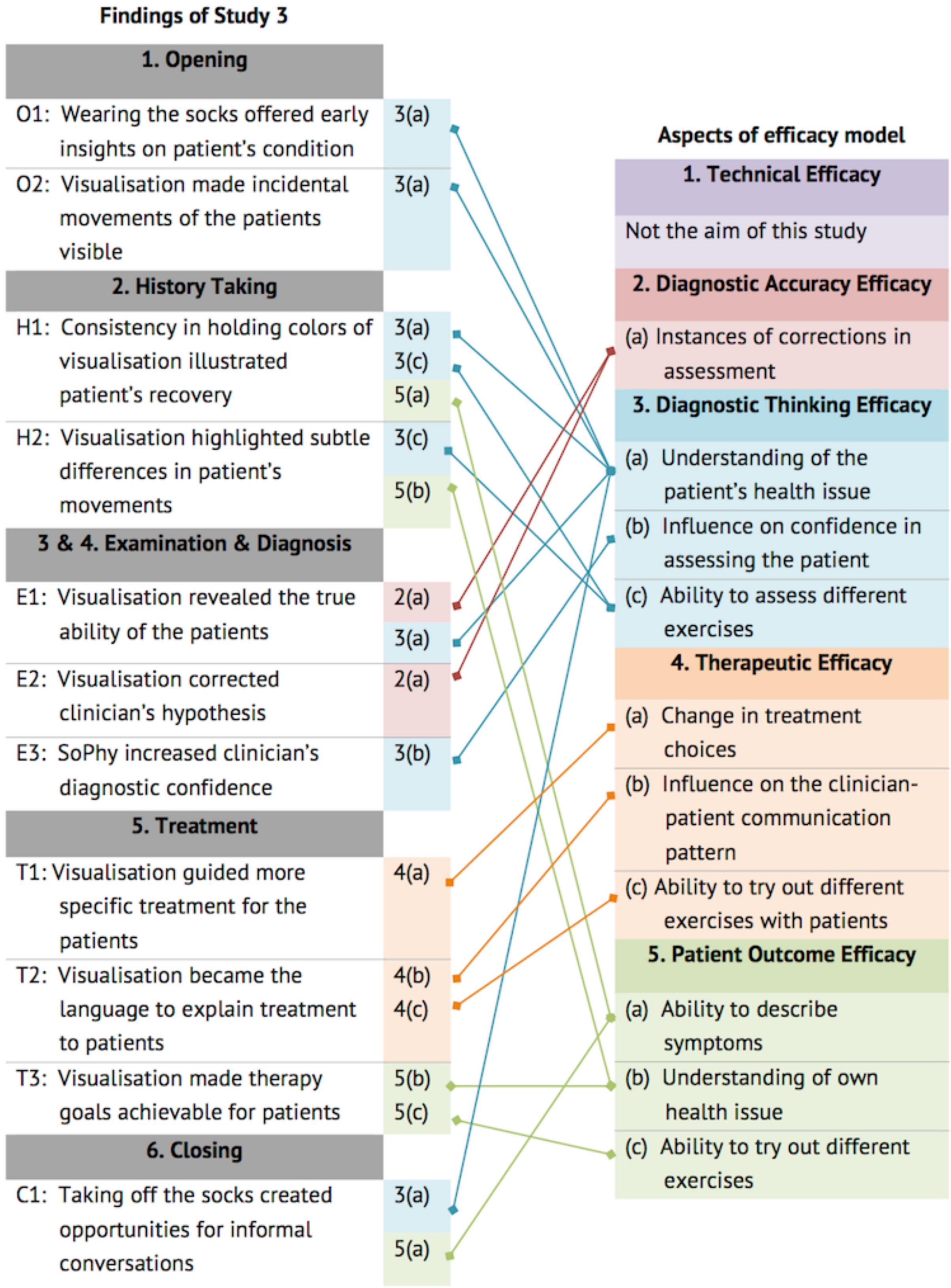


Figure 7-9: The mapping between the study findings across six phases of video consultations to different aspects of the efficacy model.

I have used stick diagrams to illustrate the study findings. Key person such as a patient and a physiotherapist in the image is highlighted in blue color. All these images are created from the field notes. To this end, the snapshots of the *SoPhy* visualisation are only the representative of the actual visualisation seen by the participants in the sessions.

Phase 1: Opening

This is an introductory phase which is dedicated for the patient and clinician to establish a rapport. In this phase, following bodily cues were relevant in face-to-face and video consultations: patient's movements, characteristics of movements, quality of movements and body posture.

O1: Wearing the Socks Offered Early Insights on Patient's Condition

The act of wearing 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 patients wore the sock first, whether they asked for any help from their parents, and how easily they were wearing them. For instance, in session 5 (face-to-face), Paige swiftly put on the socks without any help and hesitation, which was not the case in earlier sessions (session 3 & 4). Phil compared Paige's condition across three sessions (session 3, 4 & 5) by her way of wearing the socks in the interview after session 5, he said: *"Wearing the socks was more natural for her today. It showed to me that she is less anxious now and that she would be open to try out new things."* 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.

Phil utilised the same strategy of observing patient's style of putting on the socks in video consultations, when the *SoPhy* web-interface was connected a couple of minutes prior to the video connection (as per the study protocol to extend the opening). Through the 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 think-aloud manner, *"Okay, Sally is wearing the socks now, first in the left foot. The toe sensor is still orange but it is consistently orange. Now she is wearing 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!'."* Consequently, just through the interface readings, Phil understood that Sally had improved significantly and that she had started using her left foot more normally.

O2: Visualisation made Incidental Movements of the Patients Visible

Physiotherapists 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 face-to-face and video consultations. In face-to-face sessions, it highlighted the patient's health status by highlighting mundane activities like sitting posture, which were easier to ignore because of the ongoing informal conversations. 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 reflected her sitting pattern with weight on outside of her feet (as shown in Figure 7-10). 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."* Reflection on sitting posture also became the starting point for other patients and different activities unfolded from then onwards.

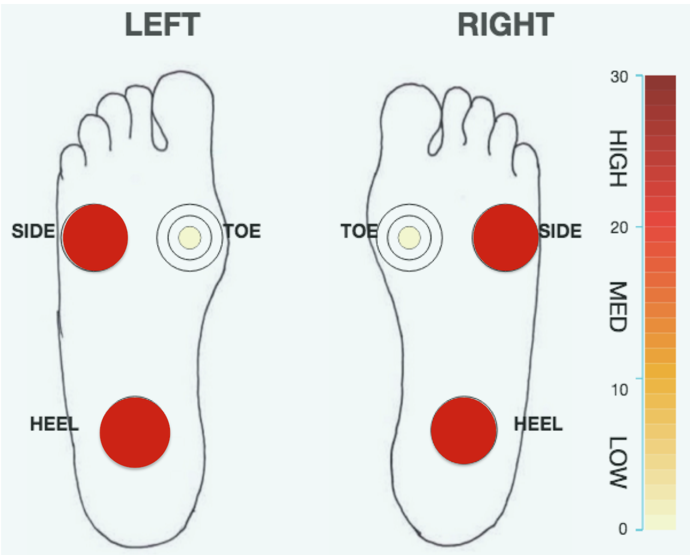


Figure 7-10: A snapshot of the *SoPhy* visualisation presenting Sally's sitting style.

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 to focus the camera on 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 7-11). He was curious to know the reason behind this visualisation, therefore after a bit of small talk, he said, *"Now Sally, please stay at the same position. Don't move. I am trying to understand your foot position through this*

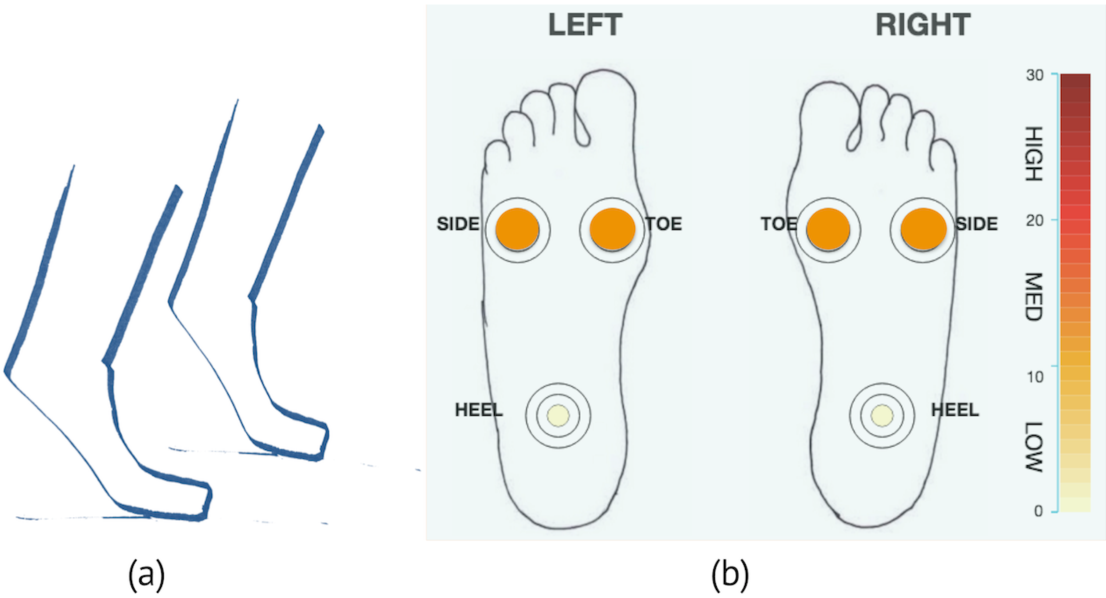


Figure 7-11: A snapshot of the *SoPhy* web-interface showing Sally's feet arrangement while talking.

interface. What are you doing right now?" Sally mentioned to be sitting in the tip-toe position. Phil was delighted to see that and with a laugh he said, *"This is amazing! I can see what's happening with your feet without even seeing it."* Phil then asked her to try to put her feet flat on the ground, and from there the session unfolded to the next phase when Sally demonstrated different exercises.

Phase 2: History Taking

In this phase, patients described their recovery since the last consultation and performed different exercises. In this phase, the following bodily cues were found important: movements during exercises, fine-details of the movements, quality of movements and body posture.

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 for different sensors attached on the affected foot. Consistency in holding colors on the *SoPhy* interface provided different pointers to physiotherapist about the patient's recovery. Firstly, it provided a way to evaluate 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 this strategy helped him to assess Paige in session 3 (face-to-face): *"In this session, she* *was mostly in the orange color spectrum but was getting other hotter colors on other parts only for a short while. So, she was holding her foot down for several seconds and the color was yellowish-orange, but only for a fraction of second she could get red color and then she would lift it up. So, I could see that she was improving – she started to put her foot down. But her progress was very slow."*

On the other hand, consistency in getting similar colors on certain areas and not on other areas also shed insights on other physical aspects of patient's status, 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) was improved. This inconsistency in colors was more evident when she was doing assisted squats, where she was going down only for a little distance and then quickly coming up. Through this, Phil understood that it could be because of the muscle tightness. Phil then inquired about how she was feeling near her calves by saying, *"Sally can you see that the heel sensors are orange when you are doing 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 Patient's Movements

SoPhy helped Phil to distinguish the subtle difference in the 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 strike patterns through the visualisation. Seeing this, Phil pointed towards the pressure sensor under 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 tried a couple of repetitions for walking. In the interview afterwards, Phil appreciated the visualisation in the following way: *"I was really amazed by seeing the walking about how clearly it [visualisation] shows the shifting of weight during walking. Being able to see what was happening there so clearly in real-time, that was a real surprise."*

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 need to improve. He compared the accuracy of *SoPhy* with their current practise, where they utilise weighing scales to understand the amount of weight patients can bear on their affected foot. He described the difference in the following way: *"They could easily cheat by pushing through their toes or through their heel - the scales would still indicate* *more weight. I would not know where their weight is if their foot looks flat. I would think that they have improved their weight bearing and they are better now. But this device is fantastic- it lets me know very clearly what they are up to. I can say that it [weight] is on the outside or it's on the inside."*

Knowing the potential of both *SoPhy* and weighing scale individually, Phil utilised both in session 5 (face-to-face) to understand the progress of Paige in bearing weight on left foot. Phil was working with Paige towards bearing her full body weight on her left leg, from the last couple of sessions. But Phil was not sure how she was pushing weight on the weighing scale. So, in this session, when Paige was pushing through the scale, Phil checked the interface and noticed that the sensor under big toe was orange, while the other sensors were red (refer to Figure 7-12). This assured Phil that she was not pushing the weighing scale from the outward side of her foot, as she was also bearing weight on the inside of the foot. In the interview, he described how the visualisation provided pointers on Paige's recovery, *"This [SoPhy] gave me more ideas of the weight distribution then. I could see that she was still bearing more weight on the red zone but still there is a significant progress in her. Her foot looks flat now and she had orange color on the ball. She is getting there."*

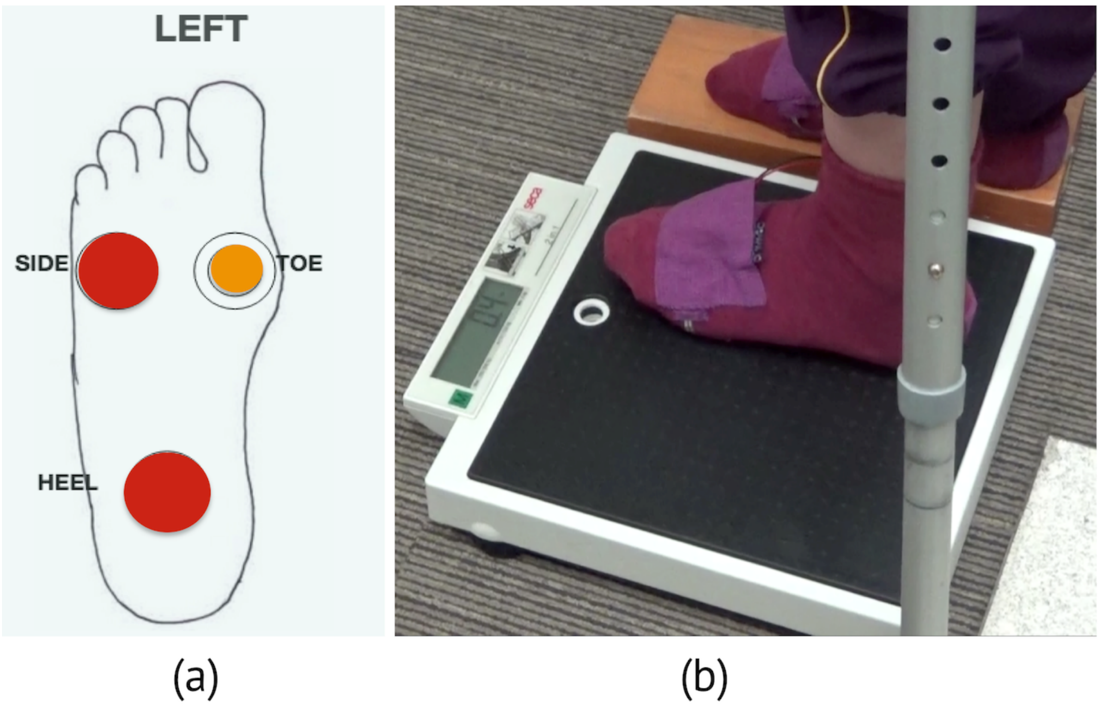


Figure 7-12: Phil used *SoPhy* along with a weighing scale to better understand Paige's weight bearing patterns on her affected foot.

Phase 3 & 4: Examination & Diagnosis

During these phases, physiotherapists performed oral and physical examination of the patient to assess the health issue. Essential bodily cues in this phase included body movements, characteristics of movements, quality of movements, posture, touch and pain characteristics.

E1: Visualisation Revealed the True Ability of the Patients

Information presented by *SoPhy* helped the physiotherapist to understand true ability of the patients, which may be different from what people say they are able to do. In the study, patients often demonstrated contradictory behaviours when their movements did 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: *"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. So that showed me that she could do better in weight bearing, but for some reason she wasn't doing it. She just kept on saying that it was painful."* Seeing this, Phil tried to encourage her to put more weight on her affected (left) foot through different exercises.

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. Paige described all the exercises as very painful. And along with the verbal complaints about pain, she was making groaning sounds like 'aah' and 'mmm'. She frequently mentioned feeling tired and took permission from Phil to sit down. All these expressions illustrated that she was going through a lot of pain and that she was putting in significant efforts in performing these movements. However, Phil noticed that these behaviours were contrary to the visualisation readings. The toe sensor for left foot consistently remained on yellow-orange color, highlighting that there was no difference in her movements. The interface then prompted Phil to observe other bodily cues such as face color and breathing patterns to understand what was going on with Paige. These observations were complemented by the interface readings and he was assured that he would need to try out some other treatment strategy with her.

In the interview after session 4, 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. She did not have any of that. She was not doing anything different today. I could see here that the colors [of the sensor visualisation] were not changing. She corrected her position and all those cues that I use to tell where* *her weight bearing is, and there was no way that I could detect it [without SoPhy]. I was really amazed, 'I mean aah! This is assessment - assessment in big time!"*

E2: Visualisation Corrected Clinician's Hypothesis

SoPhy helped Phil in correcting his assessment during 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 that and he said, "*You are putting more weight than I thought you would. You have improved Erica."* Hearing this, Erica said, *"I have been practising a lot at home."* Later in the interview, Phil appreciated the accuracy offered by *SoPhy* in the session: *"Through this device, I realised that Erica has improved in her weight bearing. I was not expecting it. I thought she is just touching down but then it [SoPhy] showed me that she was doing more than that."*

In session 4 (video consultation), Phil thought that Paige was bearing good weight as her foot looked flat on ground when she was standing. She was standing relatively straight with flat feet but 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 that she had not improved with her weight bearing on left foot. Later in the interview, Phil stated that, *"For me, it looked normal - her foot was flat on the ground. It was a very slight difference, it's in millimetres. I could not say how much weight she is bearing through her hands, it looked normal. But I could see it from the device that there was only a fraction of weight going through her feet but no more than that. My visual capacity is very high. But for SoPhy to show something so small, that's pretty revealing. The device [SoPhy] was fantastic for that to let me know really clearly that she has not got to that point yet."*

E3: SoPhy Increased Clinician's Diagnostic Confidence

The rich information provided by *SoPhy* visualisation increased Phil's confidence in assessing 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 SoPhy. SoPhy confirms what I have been thinking, takes it further or disputes it but it gives me more information. It gives me much more clear knowledge of what's happening with the patient, it shows their progress or lack of at that particular moment."*

Because of the support from *SoPhy*, Phil described *SoPhy* as a valuable resource for both face-to-face and video consultations. However, he valued it more for video consultations because over video he has limited ways to support his assessment and treatment: *"In face-to-face, SoPhy is secondary or one of the several tools I have for assessment. It works with my visual input to be able to clarify how much weight is going through it. It mainly confirms what I am already thinking. But in video, it becomes a major way of assessing what they are doing. There it's important for both assessment and treatment. I am much more reliant on it. Otherwise, I only have what I can see on the screen and that is only a limited amount of information. I can't move around the client to look them from sideways. I am stuck with a rectangular box."*

Phase 5: Treatment

In this phase, after reviewing the patient's recovery, physiotherapists recommended different exercises to the patient. The key bodily cues in this phase were fine-details of patient's movements, quality of movements, body posture during exercise, facial expressions, hand gesture and touch.

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. Phil explained the influence of greater confidence in the assessment in the following way, *"It [SoPhy] makes my intervention more accurate and more specific. It gives me more clarity about what's happening right now. I can be much more specific with where we go from now - whether we look at upgrading what we are doing because things are better, or whether we need to change. Like if I see their walking pattern is deteriorating, then it's too hard - I need to back it off."*

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 improvement in weight bearing. In session 2 (video consultation), from the beginning of the session, Phil observed that Sally could get red colors on the *SoPhy* interface throughout both feet. Phil tested her ability by asking her to perform different weight bearing exercises one after the other, 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 consultation, he practised a completely new set of exercises with her.

At other times, Phil also withdrew the treatment by seeing negligible progress in 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 were consistently showing yellow color for all the movements she performed. She was too scared to try out anything that she was not able to progress. Continuing in the same direction would not yield any fruitful result, and therefore, Phil took a step backwards from weight bearing and shifted the aim to body awareness for the next consultation. As he explained in the interview after the session, *"I can't do weight bearing with her. She won't put her weight on the foot. It [SoPhy] shows that that's where she is stuck. I would not have been sure of that without SoPhy. If we try continuing with weight bearing now, it would be flogging a dead horse. So, the next session will be to increase her tolerance through body awareness, I will try meditation with her next time."*

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. Phil worked with her to practise how to bear less weight on her right foot. Unlike other patients who used *SoPhy* for the entire session, Erica used *SoPhy* only for 15 minutes because of her condition. She tried out three exercises – sitting, standing and walking with *SoPhy*. In the interview, he elaborated how he used *SoPhy* with Erica, *"She has an irritable condition. So, we have to be careful of how much weight she puts through her right foot until her pain settles down. I am okay with the amount of weight she is putting when seated. But on standing, I am not so confident that she would be able to do the same. It could make her foot really sore. So, I used it [SoPhy] to give her some sense of what she should be doing to get a certain color or size [on SoPhy interface] when moving. Weight bearing is too early for her, so it will be trial and error to see how it [SoPhy] works for her."*

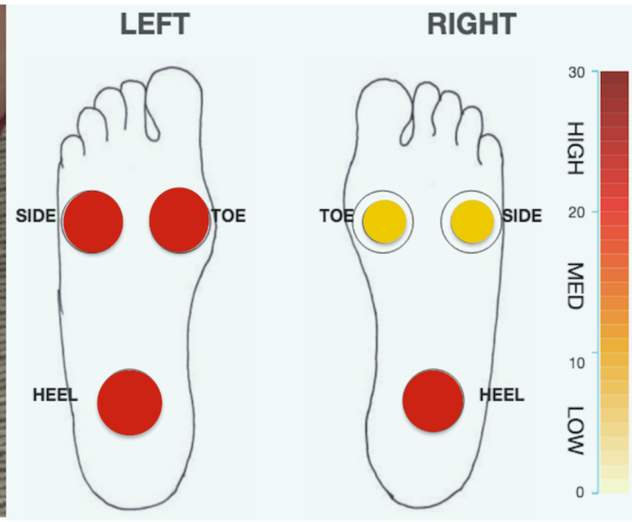
T2: Visualisation Became the Language to Explain Treatment to Patients

SoPhy provided a common language to patients and physiotherapist to communicate. Since talking about invisible bodily information is challenging, Phil described how *SoPhy* helped him to communicate the treatment goals to patients, *"The interface helped enormously in the communication. Now we understand and speak the same language. They could see all the different things I was talking about."* Phil utilised the characteristics of the visualisation such as colors, circle size and position to plan therapy goals for the patients. He appreciated the visualisation, as it provided him a rich vocabulary to converse with the patients, *"It [SoPhy interface] gives me three different sizes and it gives me all those different colors and different areas that I can use to work* *with them. 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 significantly 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."* On the other hand, 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 little weight, Phil mentioned 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 7-13).

SoPhy also became a language to discuss the patient's progress over time in a more direct and easy way. In session 4 (video consultation), Phil compared Paige's progress from the previous session (session 3) in terms of the colors on *SoPhy* interface. 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 the brown color on heels for about 7 seconds and that was longer than what you did before. So, it's a very small progress."*

(a)



(b)

Figure 7-13: *SoPhy* visualisation helped Erica to understand the correct weight distribution pattern on her affected foot. Because of her irritable condition, she was suggested to only fill yellow color on the balls of her right foot.

Better communication with the 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 practise. For instance, in session 2 (video consultation) with Sally, Phil tried a completely new set of exercises that included calf stretches, knee extensions, 1-leg stance, 1-minute step test and low squats (as shown in Figure 7-14). To try out these exercises, Phil performed multiple tasks simultaneously.

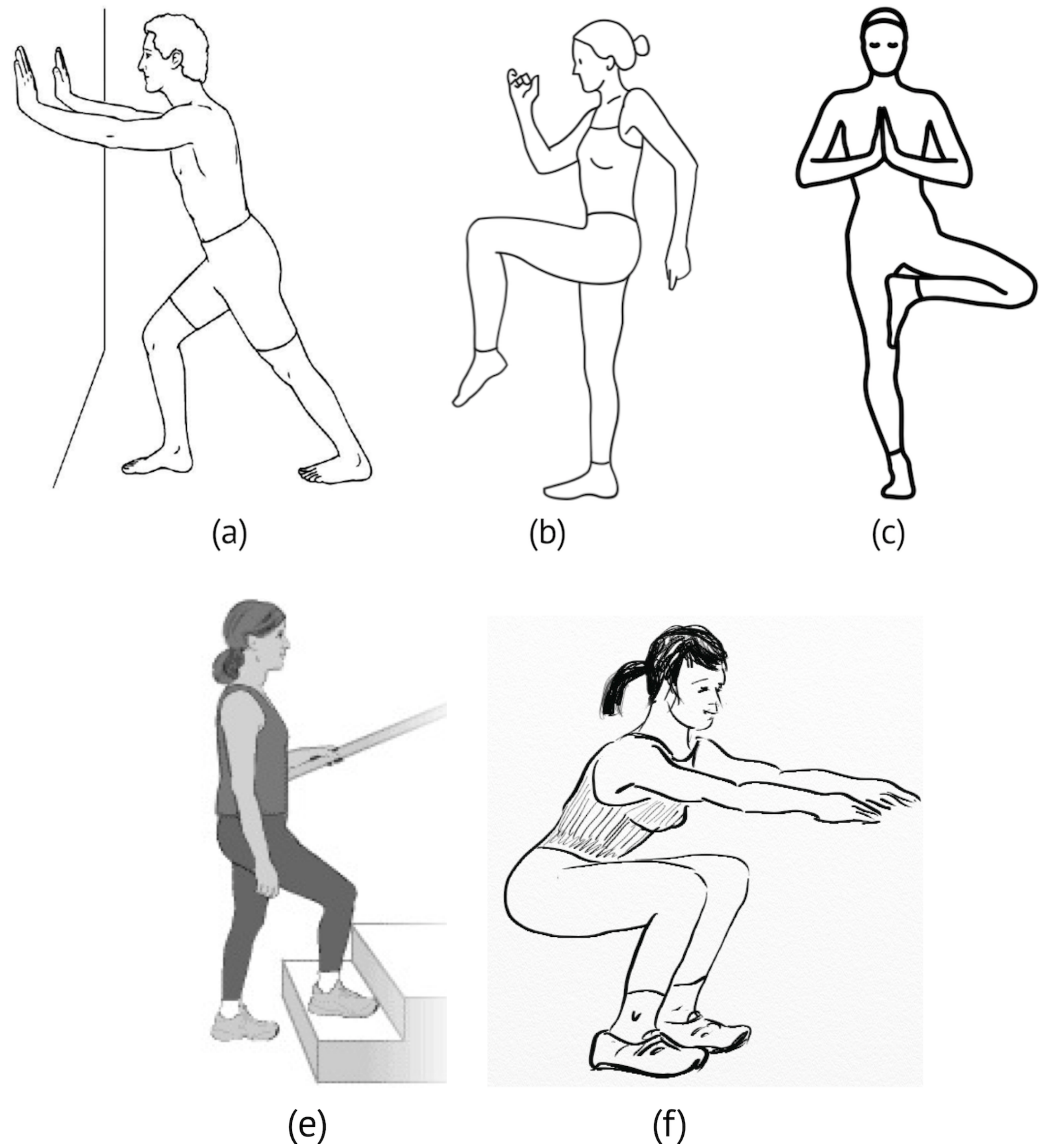


Figure 7-14: Phil tried several new exercises with Sally in the video consultation: (a) calf stretches, (b) knee extensions, (c) 1-leg stance, (d) 1-minute step test, and (e) low squats. 1-minute step test was practised with a piece of paper.

Firstly, Phil described the aim of each exercise to Sally, then he demonstrated it over video by rearranging the webcam whenever required. He then guided her on how to position herself in front of the camera for a better view. And when she was doing the exercises, he continuously checked on how she was doing it, and corrected her whenever required by showing how to do it correctly. He also used the stopwatch of his mobile phone to time Sally when she was doing 1-leg stance. Since steps were not available in the room, they practised with a paper considering paper as a heighted object. Phil was very pleased seeing the changes in his practise 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. There is a bit of separation, I can't be there to correct them. With* SoPhy*, I went through different exercises with them, 'Can you do this', 'Can you do that'. I was clear then that they knew what I was talking about. It [SoPhy] is a common shared experience now."*

T3: Visualisation Made Therapy Goals Achievable for Patients

SoPhy visualisation made the activity goals explicit to patients. Firstly, it highlighted the specific small area where they need to work on, and suddenly their therapy goals became much simpler for them to work on as well as to achieve. Patients could make simpler goals with *SoPhy*, e.g., making the circles bigger, or having slightly more colors, which seemed achievable to patients. As described by Sally in the interview, *"It is difficult to understand what to do, especially how to do like how to have normal walking. But with this [interface], you clearly know that you need to fill this circle with red color. The device is designed very well to see things in real-time."* Seeing the dynamics of *SoPhy*, Paige described the system as a game, *"you gotta balance all the dots here."*

Secondly, through *SoPhy*, patients received real-time feedback on the little changes in the movements that were difficult to understand otherwise. Without *SoPhy*, patients had uncertainty about how much weight they were bearing, and how their weight distribution pattern change for different movements. Phil described that the presence of *SoPhy* made a significant difference because it allowed them to see what's going on with them and how things change with different movements: *"When I 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."*

The visual feedback encouraged functioning of different senses in 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. The multi-sensorial sensation helped patients to overcome their anxiety and fear of bearing weight on their foot. And with reduced anxiety, patients could concentrate more on their movements. Phil described the influence of *SoPhy* on the patients in the following way, *"This device is particularly useful when fear and pain co-exist, and when clients have a long-standing condition. Like with Erica, she has a 2-year history of pain that she cannot walk properly. She probably has lost some proprioceptors, that's the capacity to feel stimulus. Because it [SoPhy] externalizes what is happening with their foot, they do not have to rely on their sensations. It just reassured them about what we are saying about fear, that they do not need to protect themselves now, and that they can do things more normally now."*

In the interview, Sally described herself being more confident in doing exercises because of the visual feedback. She said, *"It gave me lot more ability to do movements fluidly. I was confident that my foot can take the pressure, and I could see it clearly."* Seeing the importance of visual feedback, patients and parents also expressed their interest to continue using *SoPhy* at home. As quoted by Sally, *"If you have this [SoPhy] at home, you can realise that you are doing what they want you to do, and if it is the same as you were doing with them. Often you are not sure whether you are doing alright. Then you can correct and adjust yourself to do what is expected."*

Phase 6: Closing

This is the last phase where patients took leave from the physiotherapists. In this phase, physiotherapists checked patient's movements, quality of movements, body posture, facial expressions, and tone of speech.

C1: Taking Off the Socks Created Opportunities for Informal Conversations

Taking off the *SoPhy* socks created opportunities for Phil to introduce informal conversations with patients. When patients were taking the socks off, they continued talking about what worked and did not work in the session. For example, patients talked about the best moments with *SoPhy*, the peak color they could achieve at the affected area as well as the breakdown times of *SoPhy*. In this way, *SoPhy* provided opportunities to the patients to express their emotions about the consultation. On the other hand, Phil observed how the patients were taking the socks off and what kind of conversations they raised, as it provided clues related to the emotional standing of the patients with the overall session.

Closing of the sessions however, varied with different patients because of their different emotional standing. For example, ending of the sessions 1 & 2 with Sally was very positive. In both the sessions, she talked about certain moves from dancing as she wanted to resume her dancing shortly. In session 2, she demonstrated certain dance movements (e.g., swinging the leg in the air, lunges, and leg kick) to get Phil's confirmation if the movements were fine for her to perform. Following the study protocol, when Phil came down to meet her in the other room for the face-to-face follow-up, he showed her some new movements such as 1-minute step test to improve her flexibility. (He showed this exercise over video as well in the Treatment phase, but he demonstrated it again using the facility available in the gymnasium room of the hospital.) After session 2 (video consultation), Phil described Sally's behaviour in the following way, *"That was an example of feeling confident. She was thinking ahead of time. She felt that what she has done in the session was very helpful. It was such a new experience for her. She was so impressed and delighted that although we had finished, she wanted to add more things on, 'What about this', 'Should I try that'."*

On the other hand, Paige expressed her disappointment with the overall session in session 4 (video consultation). She felt disappointed because in the session, she realized that there was no change in her condition. Her high pain was limiting her movements, and she felt frustrated with it. While removing the socks, in a harsh tone, she said, *"So, what do you want me to do now?"* Phil discussed how to manage her pain and encouraged her to overcome her anxiety. Phil did not conduct the face-to-face follow up with her, as it was not required for her. Her behaviour however, changed in session 5 (face-to-face) when Paige removed the socks by herself. She was very happy with her progress in the session. She talked about the plans for her birthday party, for which she was eagerly waiting. Similarly, with Erica in session 6 (face-to-face), the ending included Phil talking about different strategies to manage her pain at home and at school.

Technical issues in using SoPhy

The study also highlighted certain technical difficulties of using *SoPhy* in the session. Some of them were expected following the insights from the laboratory evaluation of *SoPhy* (refer Chapter 6 for details). For instance, there were Bluetooth disconnects when the patient was performing exercises wearing on the *SoPhy* socks. Making the reconnections took away some time of the consultation, and reduced Phil's trust in *SoPhy* because he was uncertain of how much time would be needed to re-establish the connections. Similarly, there was delay in rendering the sensor values on the visualisation. For example, the pressure sensors did not switch to zero as soon as the weight was released, and the visualisation showed colors for little longer than the actual movements. This made it difficult for Phil to understand if the patient was bearing any weight on the affected foot, or it was the residual value from the last movements. Whenever he had doubts with the visualisation readings, he confirmed with the patient to know their actual movements.

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.

Third issue was the mismatch between the display of the patient's rested foot on the interface against the actual position. This mismatch was caused by the way IMU sensor works attached on the socks. For instance, the IMU sensor requires calibration for every single use. The sensor takes the xyz coordinates of the foot in the resting position and then processes the relative range of movement. Irrespective of the initial position of the patient's foot, the visualisation always shows the foot in rested position (refer Figure 7-15). This representation however, conflicted with patients as they already had some degree of flexion in their affected foot. For example, Paige typically stretched out the affected foot more than the good foot. Similarly, Sally kept her affected foot such that her toes were vertically up in the air and the heel was touching the ground. Consequently, patients were confused about the accuracy of the range of movement visualisation, as the visualisation showed zero flexion for their sitting position. To remove their confusion, I explained the working of the sensors whenever required.

Finally, the last issue was related to the lack of opportunity to revisit the exercises in video consultations. Patients found the visualisation so helpful that they wanted to see it for every exercise they performed, which however was not possible in video consultations. For instance, patient's orientation with respect to the *SoPhy* web-interface changed in different exercises and for certain exercises like walking, they were not in

Figure 7-15: The mismatch between the patient's actual rested foot and the visualisation displayed on the interface: (a) Sally and Paige had some degrees of flexion in their affected foot, but (b) the *SoPhy* web-interface showed rested foot for these positions.

front of the screen to see the visualisation. Some other times, patients closed their eyes to concentrate on the exercise, and hence could not see the visualisation. Although patients mainly appropriated their positioning to see the visualisation in video consultations, the rearrangement did not help at certain instances. Interestingly, patients and physiotherapist found a solution for this challenge in face-to-face setting. Physiotherapist made video recordings of the visualisation and/or patient's movements along with the help of the patient's carer. Patients and physiotherapist watched these recordings later to discuss the patient's progress.

7.6. Discussion

The study highlighted that *SoPhy* increased the efficacy of video consultations across all phases of video consultations. *SoPhy* was used by a physiotherapist to normalise weight bearing of three patients having different chronic pain conditions. *SoPhy* provided key information about weight distribution, foot orientation and range of movement that was essential for physiotherapists to assess and treat patients over video. Access to these bodily cues, from the beginning till the end of the session, increased physiotherapist's confidence in assessing patients. Increased confidence in assessment guided specific treatment for patients, where physiotherapist appropriated the treatment based on the current health status of the patient. Additionally, *SoPhy* visualisation became a common language to talk about the patient's recovery and to plan the therapy goal, which in turn, also enhanced patient's efficacy in achieving therapy goals. As such, with *SoPhy*, the consultations became interactive, and the physiotherapist tried out new and varied activities with patients that he never tried over video earlier.

Below I will answer the sub-questions formulated in the beginning of the chapter, and I will discuss how the use of *SoPhy* addressed the four aspects of efficacy model – *diagnostic accuracy, diagnostic thinking, therapeutic* and *patient outcome efficacy.* To highlight the impact of *SoPhy* in video consultations, I will also compare the findings of this study with the challenges identified in Study 1 (refer to Table 4-3 of Section 4.6 for the list of challenges). Table 7-4 lists the findings of this study corresponding to different challenges of Study 1 across all phases of a video consultation. Challenges of Study 1 follow the same numbering as used in Chapter 4, i.e., C1, C2 and so on, and the findings of Study 3 use the same nomenclature with names around the phases.

As shown in the Table 7-4, *SoPhy* resolved all the challenges identified in Study 1, except for two challenges - C2 and C5. Firstly, involving multidisciplinary clinicians (C2) continued to be an issue in this study and sessions involving different experts were not organised over video. This issue thus, influenced the course of the study, where the third session with Paige was organised in face-to-face setting instead of a video consultation, which contradicted with the study protocol. On the other hand, I did not observe any

Challenges identified in Study 1	Findings of Study 3
Phase 1: Opening	
C1: Limited availability of incidental cues	O2: Visualisation made incidental movements of the patients visible
C2: Involving multiple clinicians was challenging	**(remained a challenge)**
C3: Limited opportunities for small talk	O1: Wearing the socks offered early insights on patient's condition
Phase 2: History Taking	
C4: Reliance on verbal explanation to understand symptoms	H1: Consistency in holding colors of visualisation illustrated patient's recovery
C5: Inability to control field-of- view caused awkwardness to patients	**(not observed in this study)**
C6: Subtle differences in exercises were difficult to observe	H2: Visualisation highlighted subtle differences in patient's movements
Phase 3 & 4: Examination & Diagnosis	
C7: Hands-on examination was not possible	E2: Visualisation corrected clinician's hypothesis E3: SoPhy increased clinician's diagnostic confidence
C8: Covert examination was challenging to perform	E1: Visualisation revealed the true ability of the patients
Phase 5: Treatment	
C9: Limited scope to recommend new exercises	T1: Visualisation guided more specific treatment of the patients T2: Visualisation became the language to explain treatment to patients T3: Visualisation made therapy goals achievable for patients
Phase 6: Closing	
C10: No room to accommodate afterthoughts	C1: Taking off the socks created opportunities for informal conversations

Table 7-4: *SoPhy* resolved the challenges related to bodily communication, as recognised in Study 1.

awkward moments in this study (C5) because all the exercises were performed in sitting and standing positions. Awkwardness could have been an issue if there were patients with hip pain or back pain, where they may need to face against the camera with no control on their field-of-view. Now let us look at how *SoPhy* addressed the study goals.

Diagnostic Efficacy

In response to the first sub-question (Q1), *SoPhy* enhanced the diagnostic efficacy of physiotherapists by improving their *diagnostic thinking ability* and *diagnostic accuracy* to assess patients during video consultations. *SoPhy* increased the thinking ability of the physiotherapist from the opening of the consultation by providing rich insights on the patient's emotional and physical state. Through *SoPhy*, Phil observed how patients were using their foot while wearing the socks, and while seated during the informal conversations. Insights on such unconscious and incidental movements of the patients offered a better reflection on the patient's condition, and hence were appreciated by the physiotherapist. On the other hand, such observations were not possible in Study 1 because video consultations started with patients directly seated in front of the camera with webcam focused on the upper torso (O2, C1). Also, as there were no activities involved in the beginning of the session, physiotherapists had little opportunities to raise small talk (O1, C3), and within less time the session moved to another phase. As such, with *SoPhy*, the physiotherapist could formulate their initial assessment from the early insights obtained.

In the History Taking phase, *SoPhy* visualisation became a crucial source for the physiotherapist to understand the patient's recovery in performing different movements. Physiotherapist got insights about the patient's anxiety, muscle tightness, and strategies of weight bearing by observing the patient's consistency in holding colors on specific locations of the visualisation. This information became conversation pointers that physiotherapist utilised to interrogate the patient. Consequently, physiotherapists were not reliant on the verbal explanation of the patients, which was the major source of physiotherapists in Study 1 (H1, C4). As described by participants in Study 2, verbal confirmation is not sufficient because often patients do not know what is happening with them and therefore, do not raise many issues by themselves. Additionally, *SoPhy* visualisation revealed the fine-details of the patient's lower limb movements, which were challenging to observe directly over video in Study 1 (H2, C6). The challenges of video consultations in Study 1 affected patients like Laura, as she was not good at providing verbal details on her recovery and had chronic pain in ankle, and hence, she was recommended to consult a local physiotherapist instead. Through *SoPhy*, the physiotherapist got information as subtle as the walking pattern of the patients that are difficult to eyeball even in face-to-face setting. All these insights provided the physiotherapist with a better understanding of the patient's condition, which guided detailed assessment of the patient.

In Study 1, assessment of the patients was limited to oral examination, as physical examination by physiotherapist cannot be conducted over video. However, *SoPhy* offered alternate ways that served the needs of the physiotherapist and fulfilled the gap of physical examination (E2, E3, C7). Firstly, *SoPhy* helped the physiotherapist in assessing patients through their movements. It highlighted the subtle differences in the movements that were otherwise not visible or misleading over video. The ability to distinguish subtle differences corrected physiotherapist's assessment at certain instances and made their assessment timely and accurate. Secondly, *SoPhy* helped the physiotherapist to conduct in-depth oral examination of the patients following the information presented on the visualisation. Interestingly, crucial bodily information like body tightness started to emerge from the History Taking phase itself, thereby, helping physiotherapists to continuously refine their assessment. Finally, *SoPhy* supported covert examination of the patient, which was identified as a challenge in Study 1 (E1, C8). For instance, the *SoPhy* socks became a probe to support covert examination, and patient's interactions with them highlighted their health status throughout the session, e.g., in the opening, during technical breakdown and at the end. Having the support of *SoPhy* enhanced the diagnostic confidence of physiotherapist and guided more detailed and accurate assessment of patients than what was observed in Study 1.

SoPhy continued to offer diagnostic support to physiotherapists to better understand patient's condition until the end of the video consultation. In fact, *SoPhy* became an excuse to extend the ending of the video consultation, as patients were required to take off the *SoPhy* socks. Physiotherapist got opportunities to initiate informal conversations with the patients, and consequently understood the satisfaction and confidence of patients with the overall consultation. During these conversations, patients expressed their happiness and disappointment with the session, which helped the physiotherapist to understand their physical and emotional state. This addresses the issue found in Study 1 (C1, C10), where the ending was short and physiotherapists were again reliant on the verbal explanation of the patients to understand any outstanding issues.

Therapeutic Efficacy

Increased confidence in the assessment contributed to the *therapeutic efficacy* of the physiotherapists, which answers the sub-question Q2. After seeing the progress of the patients through *SoPhy*, the physiotherapist could validate the effectiveness of his treatment for a patient at different times, which was not even possible in Study 1 (T1, T2, C9). For instance, in Study 1, because of the lack of the available bodily cues from the start of the session, physiotherapists were not sure of what treatment would be best for the patient; and hence, they generally continued with the previously recommended treatment. In contrast, with *SoPhy*, physiotherapist appropriated their treatment to make it more suitable for the patient's current health status. For example, Phil upgraded the treatment to next therapy goal for Sally, and took a step backward to the previous therapy goal by seeing Paige's negligible progress in weight bearing. As a result, Phil described his treatment being more specific and accurate with *SoPhy* (T1).

Additionally, the *SoPhy* visualisation improved the communication between patient and physiotherapist by offering them a common language to talk about the non-verbal bodily cues that were otherwise difficult to converse (T2). The physiotherapist utilised the characteristics of the visualisation such as colors, circles and location of sensors to discuss the patient's progress and to plan the future activities. *SoPhy* was used in two ways: Firstly, to help patients in learning normalised weight bearing where the physiotherapist highlighted specific locations on the visualisation to fill in more colors, as was the case with Sally and Paige. Secondly, it was used as a training tool to explain how to put less weight on the affected foot, which was essential for Erica's condition. Moreover, depending upon the patient's condition, the duration of the use of *SoPhy* also varied. For example, while Phil used *SoPhy* for the entire session with Sally and Paige, *SoPhy* was used only for 15 minutes with Erica because doing lots of movement was not advisable for her irritable condition. With *SoPhy*, Phil was confident that patients knew what they were talking about, which encouraged him to try out different activities with patients over video.

Along with the benefits of *SoPhy*, the study also highlighted certain issues with the visualisation. For instance, the subtle differences in the continuous color spectrum of the visualisation limited their communication. The physiotherapist found it challenging to verbally refer to these colors during the video consultations. I will discuss ways to tackle this challenge in the next section.

Patient Outcome Efficacy

In response to the third sub-question (Q3), *SoPhy* also contributed to the *patient outcome efficacy*. Firstly, *SoPhy* helped the patients in describing their symptoms by providing pointers to the physiotherapist about their physical and emotional status (H1). Physiotherapists utilised these pointers to inquire patients about their conditions, and thus patients could talk about the issues that they would not describe otherwise. Such a support from *SoPhy* was helpful for patients because often patients are not aware of the strategies they are applying to cope with their condition and hence, they would not describe these conditions to the physiotherapist. This finding resolved the issue found in Study 1, where patients were expected to describe their symptoms verbally (H1, C4).

Moreover, the visual feedback of *SoPhy* provided better understanding of their health issue to patients. *SoPhy* made the therapy goals direct and achievable for patients (T3), as it highlighted the exact location on the affected foot that required more efforts from the patients. In long-standing conditions, physical sensations on the affected foot are mixed up, and the differences in movements are not clear. But the real-time feedback through *SoPhy* helped patients to reflect upon their progress by understanding the difference between what they were doing as opposed to what they should be doing. *SoPhy* helped patients differently at different time, e.g., for Sally, *SoPhy* provided an assurance that she could bear more weight on her affected foot; whereas for Paige, *SoPhy* first acted as a confrontation tool by highlighting her lack of efforts and then acted as a confirmation tool on her progress. *SoPhy* offered an alternative sensation to these patients, which helped the patients to redirect their attention from pain to their therapy goals. Consequently, patients could overcome their anxiety and perform better in the presence of visual feedback.

Lastly, *SoPhy* also supported patients at the end of the consultation. Because the ending of video consultation included removing the *SoPhy* socks off, patients had the opportunity to express their emotions with the consultation, which was not possible in Study 1 (C1, C10). For instance, Sally utilised this opportunity to express her excitement with her recently recovered condition, whereas Paige expressed her disappointment with the treatment. However, apart from the benefits, patients also faced certain issues in using *SoPhy*. Firstly, the subtle differences in the continuous color spectrum did not give them a sense of accomplishment in reaching their goals. Also, there were no opportunities to revisit their exercises for collective reflection with the physiotherapist. I discuss different ways to approach these issues in the next section.

7.6.1. Design Considerations

The study also highlighted certain issues with the use of *SoPhy*, especially for the treatment purposes, as the continuous color spectrum limited the clinician-patient interactions. Additionally, the use of *SoPhy* in face-to-face consultations also revealed opportunities for refining *SoPhy* to enhance the experience of video consultations. Based on the gained understanding, below I provide three design considerations to design wearable systems like *SoPhy* for video consultations.

Supporting Customisation of Technologies for Different Phases of Rehabilitation

Technologies for remote rehabilitation should support customisation so that it can be appropriated based on the different needs of patients. As such, the designed video consultation system should support setting up goals in real-time and changing them as per the patient's condition to cater to the varying needs of clinicians and patients. In this study, Phil used *SoPhy* differently with different patients, e.g., Erica learned how to bear less weight on the affected foot, and Sally and Paige learnt how to start bearing more weight on their affected foot. Also, the duration of use of *SoPhy* varied depending upon the patient's condition, with Erica using it for 20 minutes and the other two used it for the entire consultation. Although *SoPhy* was primarily used for sitting and standing exercises, it could also be used with patients who are in the early stages of rehabilitation where putting the foot down on the floor is not the immediate step. Physiotherapist can ask the patients to lie down on the bed and start putting their foot flat while wearing the socks. *SoPhy* can then show the balance of patients in lying position. In this regard, physiotherapists would need to appropriate *SoPhy* to make it suitable for different patients. And to support this, physiotherapists require more control on the visualisation, so that they can hide or highlight main aspects of patient's movements on the visualisation.

Additionally, *SoPhy* was used with patients having weight bearing issues. Normalising weight bearing patterns of patients is only one aspect of lower limb rehabilitation. *SoPhy* needs to be further developed to support the next goals of rehabilitation around endurance and flexibility. Endurance and flexibility are mainly achieved by repeating the same exercise for a certain number of times to support motor training (Dillman and Tang, 2015). In this regard, such technologies should support quantification of movements in terms of repetitions, time taken to perform a set of repetitions, and movement patterns over time. This rich information need not to be automated, but rather it could also become a part of manual logging process of everyday routine of the patients, which was also observed in Study 1 (discussed in Section 4.4.2). Being remotely available in video consultations, different patterns of movements is much needed to support rich conversations between patient and clinicians, where the presented information will provide conversation pointers to participants.

Greater Support for Collective Reflection on Therapy Goals

By collective reflection, I refer to the process when both patients and clinicians are involved in discussing the patient's recovery and to plan 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 goal-setting theory (Locke and Latham, 2006; Winstein et al., 1994). In video consultations, as patients and clinicians are present in different physical spaces, achieving collective reflection is challenging and for the same reason, it is more important to create a shared remote experience. One way to support collective reflection could be by supporting bodily communication with and around the technology offering feedback on the patient's movements. The use of *SoPhy* in face-to-face consultations highlighted certain bodily interactions with *SoPhy* that made the clinician-patient interactions more spontaneous during the session. For instance, physiotherapists frequently touched and gestured towards the visualisation to plan goals for the patients. 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.

Another way could be by providing physiotherapists opportunities to revisit the patient's movements through snapshots of the screens or video recordings of the visualisation showing patient's movements. When *SoPhy* was used in face-to-face consultations, the physiotherapist video-recorded the visualisation screen and patient's movements, for certain exercises. Both patient and physiotherapist watched these recordings together to reflect collectively on patient's progress. Video recordings particularly proved beneficial at times when the patients could not refer to the visualisation, e.g., they closed their eyes to concentrate or they focused on the movements of their feet to understand the correct movement. Video recordings were not made during video consultations because of the lack of support in recording the videos and watching them together. However, these activities are rather easier to perform in video consultations because it is easier to screen record the visualisation. Collective reflection through video recordings is already explored in other setting, where the speech therapist offered video based training to parents having kids with Autism (Aggarwal et al., 2015). In the video sessions, the speech therapist video recorded a parent and child pair doing an activity at their home. These video recordings were then revisited with the parent to reflect on the progress of the parent and child as well as to plan next goals for the parents.

Making the Patient's Recovery Explicit through Visualisation

The study highlighted certain issues with the use of *SoPhy* visualisation during the communication, where the small variations in the color spectrum did not highlight the patient's recovery. The limited acuity of colors created two issues: first, it limited the communication, as the physiotherapist could not verbally refer to these colors over video. Secondly, it did not highlight the achievement of patients when they met their therapy goals. For instance, Paige was delighted to see her progress through the weighing scale, as she could compare the score from the previous sessions. Patients with long standing conditions exhibit slow progress in their health status and therefore, require greater motivation to maintain their progress.

The visualisation should provide more levels for enhancing the communication between physiotherapist and patient as well as to make patients feel rewarded with their achievement. One way could be to make the categories of weight distribution more distinct with each category following different color spectrum and a distinct ending. For example, the interface could utilise the graded color notation of rainbow spectrum with low category defined from violet to indigo, medium category from blue to green, and the highest range having the color of yellow to orange. Patients and physiotherapist can then plan the goals around these categories. Another way to enhance the visualisation is to add the exact weight the patient is bearing on each sensor - which patients can compare in different sessions in order to reflect on their progress.

7.6.2. Study Limitations

This study has certain limitations. Firstly, findings presented in this study around the utility of *SoPhy* in real world video consultations are based on a small number of patients and physiotherapists. Additionally, although two physiotherapists were recruited to participate in the study, all the sessions were conducted with only one physiotherapist who was involved in this research from the first study. Consequently, there is an issue that the presented findings may not be applicable to physiotherapy video consultations in general. However, in order to make the findings transferable to other contexts, I evaluated the use of *SoPhy* around different aspects of an efficacy model and structured the findings around six phases of the clinical consultations. The efficacy model and the consultation phases provided rigour in the data collection process and helped me to evaluate *SoPhy* around the clinical tasks of a consultation, i.e., assessment and treatment.

Another limitation of the study is the credibility of the collected data, as the main source of the data collection was participant observation. Hence, I may have missed out certain key activities of the consultation or may have misinterpreted certain bodily information, while taking notes in the session. However, in order to overcome this limitation, I followed Member Checking and validated the study findings with the collaborating physiotherapist who participated in the study. Additionally, I have provided a detailed account of the data collection and analysis processes both in the chapter and in Appendix D to make the data auditable.

7.7. Summary of Contributions

This study makes the following three core contributions:

1. Through field deployments of *SoPhy*, I demonstrated that the efficacy of video consultations can be enhanced by designing technologies that support physiotherapists in conducting assessment and treatment. By discussing eleven themes across six phases of video consultations, I provide an in-depth understanding of how the availability of key bodily cues to physiotherapists enhanced the efficacy of their assessment and treatment in video consultations. To the best of my knowledge, this is the first study within HCI that evaluates a novel technology for physiotherapy related video consultations through field deployments. Previously, only a couple of studies mainly in the domain of surgery, e.g., (Mentis et al., 2016a; Stevenson, 2010) have managed to conduct field deployments of new systems for video consultations. This is due to the sensitivities of the hospital setting that makes the field deployments of new devices particularly research prototypes challenging (Blandford and Berndt,

2010). Yet field deployments are needed to understand the implications of new systems in real-world setting.

2. Secondly, this study highlighted the influence of visual feedback to support rehabilitation of the patients in the context of video consultations. As patients and physiotherapist are remotely located in a video consultation, *SoPhy* visualisation enhanced their communication by offering a shared language to discuss the therapy goals and the patient's recovery. The real-time feedback on the movements offered a better understanding to the patients on how to alter their movements in order to achieve their goal of normalised movements. Better patient outcome, further boosted the treatment efficacy of the physiotherapist, as a treatment is successful only when it is suitable for the patient.

3. Finally, this study provides three design considerations to enhance the clinician-patient interactions during video consultations, namely, supporting customisation of technologies for different phases of rehabilitation, greater support for collective reflection on therapy goals and making the patient's recovery explicit through visualisation. These guidelines particularly emphasize on enhancing the remote collaboration between the physiotherapist and patient, which *SoPhy* partially supported but further investigation is required to support the collaborative process of setting treatment goals in video consultations.

7.8. Conclusion of Study 3

This study was conducted to answer the final research question on how does *SoPhy* contribute to the overall clinical efficacy of physiotherapists in assessing and treating patients with lower limb issues during video consultations. In response, I conducted field deployments of *SoPhy*, where one physiotherapist used *SoPhy* to assess and treat three patients with lower limb conditions in video consultations. Findings of the study showed that *SoPhy* increased the efficacy of video consultations and helped the physiotherapist in effectively assessing and treating patients over video. *SoPhy* supported more accurate assessment of the patients by providing rich information on both the unconscious and conscious movements of the patients. Having access to the important bodily information on the patient's movement right from the beginning of the consultation boosted the physiotherapist's diagnostic confidence. Consequently, he could validate the effectiveness of their treatment strategy for a patient at different times. As such, *SoPhy* enhanced the communication between the physiotherapist and patient during video consultations, and made the sessions more interactive e.

In the next chapter, I bring this thesis to closure by discussing the implications of different studies conducted as part of this research on the existing literature.

Chapter 8
Discussion & Conclusion

Overview: This chapter offers concluding remarks on the entire thesis and suggests directions for future research to bring the thesis to closure.

8.1. Introduction

The previous chapter discussed the final study of the thesis, where *SoPhy* was evaluated in video consultations of physiotherapy at the hospital setting. In this chapter, I will discuss the findings of all the three studies conducted to answer the main research question of the thesis, established in Chapter 1. Additionally, the chapter will also highlight the four main contributions made by this thesis to the field of HCI and related areas. Firstly, the thesis developed a detailed understanding of how physiotherapists employ bodily communication in video consultations. Secondly, it developed an understanding of the challenges faced by the physiotherapists in interpreting the patient's bodily information over video. The third contribution is a novel wearable technology *SoPhy* that communicates information related to the patient's weight distribution patterns over-a-distance, to support the diagnostic needs of the physiotherapists. Finally, the thesis demonstrates that *SoPhy* enhanced the clinical efficacy of the physiotherapists in assessing and treating patients during video consultations.

The chapter is organised in the following way: I will start by providing a summary of how the main research question is answered through three studies in Section 8.2. Section 8.3 describes the four contributions made by the thesis and its implications to the existing literature. Later, in Section 8.4 I will discuss the limitations of this work with respect to the methodological challenges of conducting research in the context of video consultations. Section 8.5 illustrates the future opportunities to conduct research in this area, and Section 8.6 offers concluding remarks to the thesis.

8.2. Research Questions Revisited

This research was motivated by the three research gaps that were highlighted in the literature review. Firstly, the review highlighted a limited understanding of how bodily communication happens in video consultations of physiotherapy, despite the fact that bodily communication is described as fundamental in traditional clinical consultations and for the domain of physiotherapy. Additionally, there was a lack of understanding on how clinicians assess and treat patients during video consultations, as the existing literature focused majorly on understanding the experience of patients and supporting collaborative tasks between the remote clinicians. However, little was known about how clinicians conduct their clinical tasks when the patient is not accompanied by an assistant. The final research gap described the limited focus on designing technologies that rely solely on video to support bodily interactions between physiotherapists and patients.

Motivated by these gaps, this thesis explored the role of interactive technologies to support physiotherapists with the bodily information required to assess and treat patients during video consultations. The main research question investigated in this thesis was:

> How can interactive technologies support physiotherapists in understanding patient's bodily information during video consultations?

I answered the main question through three studies, each study aimed at answering a sub-question formulated at the beginning of the thesis. Chapter 4 to 7 provided details on each study. I employed a mixed method approach to conduct these studies, where each study followed a distinct research methodology. Each study was designed carefully and iteratively, and was informed from the insights of the previous studies and the sensitivities of the research site. The work started from an observational study, where I investigated the challenges faced by the physiotherapists in interpreting bodily information related to the patient's movements during video consultations (Study 1). This study was followed by a design phase, where I developed a research prototype called *SoPhy* to support assessment and treatment of lower limb movements during video consultations. The design phase was followed by a laboratory evaluation of *SoPhy* (Study 2), where I investigated the diagnostic efficacy of *SoPhy* in assessing lower limb movements over video. Finally, in Study 3, *SoPhy* was evaluated in the hospital setting, where it was used by the patients and physiotherapists during video consultations.

These three studies collectively highlighted that interactive technologies play a crucial role in communicating (or not communicating) bodily information over-a-distance. Bodily communication is important across all phases of a physiotherapy consultation; However, a variety of bodily cues are unavailable in the current practises of video consultations. The reason being that video technology encompasses limited visual acuity, and therefore, understanding the subtlety of the exercises and depth of the movements becomes challenging during video consultations. The lack of bodily cues reduces clinician's confidence in assessing patients over video, which in turn, makes their treatment less specific. While video technology is insufficient to communicate the essential bodily cues to the physiotherapists during video consultations, sensor-based technologies have significant potential to accurately capture and render patient's movements - which I harnessed to design *SoPhy*. The introduction of SoPhy in video consultations supported physiotherapists in assessing and treating patients with lower limb issues over-a-distance effectively. *SoPhy* offered the essential bodily information required to assess patients quite early in the session and boosted the physiotherapist's confidence in trying out new exercises over video. In summary, the thesis illustrated that video consultations can become efficacious if the interactive technologies are specifically designed to support the communication of the essential bodily cues required to conduct the clinical tasks remotely.

Below I summarize how I answered the three sub-questions in this thesis.

RQ1:	How do physiotherapists interpret bodily information in the current practice of video consultations?

The first study utilised a field research approach to investigate the challenges faced by physiotherapists in interpreting bodily information of patients during video consultations. (see Chapter 4 for the details of Study 1.) The study was conducted at the Royal Children's Hospital in Melbourne with two physiotherapists and five patients. They were recruited from the Department of Anaesthesia and Pain Management at the hospital. I conducted observations of seven video consultations and three face-to-face consultations to understand the interactions of clinicians and patients with the underlying technology, and to understand how the interactions in video are different from the traditional face-to-face consultations.

The study highlighted that different aspects of bodily communication were limited by video technology across six phases of a physiotherapy consultation – *Opening, History Taking, Examination, Diagnosis, Treatment,* and *Closing*. The study highlighted that the assessment of physiotherapists is not limited to patient's movements; rather observations of incidental cues related to patient's movements constitute a major portion of their assessment. However, the current practice of video consultations limited physiotherapists' understanding of incidental cues, as the patients remained seated from the start of the consultation till the end. Additionally, subtle differences in the patient's movements, such as weight distribution and range of movement, were also challenging to distinguish over video. Consequently, physiotherapists had little understanding of the patient's recovery from the beginning of the consultation till the end. Furthermore, the study revealed that lower limb movements were particularly more challenging to communicate over video, as the video technology was insufficient to capture the depth and perspectives of the patient's movements. The absence of the essential bodily cues reduced the ability of physiotherapists to suggest new treatment over video, and consequently, video consultations became less effective than face-to-face consultations. The challenge of communicating finer details related to lower limb movements guided the development of a research prototype, *SoPhy*.

SoPhy is a wearable technology consists of a pair of socks and a web-interface, designed to support physiotherapists in assessing lower limb movements in video consultations. During a video consultation, when the patient wears the *SoPhy* socks and performs lower limb exercises, the sensors embedded on the socks capture the fine-details of the movements. The captured data is presented on the *SoPhy* web-interface to the physiotherapist in real-time, who is available on the other end of the video call. (Chapter 5 provides details of the iterative development of *SoPhy*.) After developing *SoPhy*, I conducted the laboratory evaluation of *SoPhy* to validate its design and suitability for the physiotherapists, which became the next study of the thesis.

The research questions explored in the second study was:

RQ2:	How does *SoPhy* influence the efficacy of physiotherapists in assessing lower limb movements in (simulated) video consultations?

Study 2 involved the empirical evaluation of *SoPhy* to understand it's potential in supporting the assessment of lower limb issues in video consultations. Following the experimental research methodology, the study happened in a research laboratory where I simulated the settings of a video consultation across two rooms. *SoPhy* was evaluated across three parameters of efficacy model: *diagnostic accuracy efficacy, diagnostic thinking efficacy,* and *technical efficacy*. Participants of this study were postgraduate physiotherapy students from the university campus, who acted as physiotherapists and conducted the assessment of a mock patient (recruited from the same cohort) for different lower body exercises. I asked each participant to organise four video consultations in total - two *with SoPhy* and two *without SoPhy*. In total, 40 video sessions were conducted. The collected data was analysed using both the qualitative and quantitative methods (see Chapter 6 for more details).

The study highlighted that *SoPhy* increased the diagnostic confidence of participants in assessing patients over video, as the participants could confirm their assessment through *SoPhy* visualisation. *SoPhy* also corrected their hypothesis by providing details of the subtle differences in the movements that were not easy to eyeball through the video stream. Moreover, the participants required fewer repetitions of exercises to formulate their assessment with *SoPhy* because *SoPhy* provided them with all the crucial information related to the patient's movements right from the beginning of an exercise. With regards to the technical efficacy, the study confirmed that the three aspects of lower limb movements captured by *SoPhy* were sufficient to conduct assessment over-a-distance. However, there were certain technical issues related to the design of *SoPhy* visualisation and socks, which affected the technical efficacy of *SoPhy*. To address these issues, *SoPhy* went through another iteration in preparation for the final study.

The aim of the final study was:

RQ3:	How does *SoPhy* influence the efficacy of physiotherapists in assessing and treating lower limb movements in hospital video consultations?

The final study included the field deployments of *SoPhy* in naturally occurring video consultations at Royal Children's Hospital. This study aimed at investigating the role of *SoPhy* in supporting physiotherapists to assess and treat patients during video consultations, and its influence on the overall efficacy of video consultations. In pursuit, I installed *SoPhy* in six consultations and conducted participant observations to understand the interactions of the physiotherapists and patients with *SoPhy*. These consultations were organised by a physiotherapist for his three patients, each having long-term chronic lower limb condition (refer Chapter 7 for more details on this study).

The study findings revealed that *SoPhy* increased the efficacy of video consultations by achieving clinical efficacy around four crucial aspects - *diagnostic accuracy efficacy, diagnostic thinking efficacy, therapeutic efficacy* and *patient outcome efficacy*. Through *SoPhy*, the physiotherapist had access to the crucial bodily information right from the beginning of the consultation that highlighted the patient's emotional and physical state. *SoPhy* was described as a valuable tool for both the assessment and treatment. It confirmed as well as corrected the assessment of the physiotherapist and thereby, increased his confidence in assessing patients over video. *SoPhy* highlighted the subtle differences in the patient's movements that were not visible directly over video. Through *SoPhy*, the physiotherapist could validate their treatment strategy at different times during the long-term treatment, and consequently, his treatment became more specific to suit the patient's current health condition. Additionally, it enhanced the clinician-patient interactions by providing a shared communication language to discuss the non-verbal bodily cues, which are otherwise difficult to converse.

On the other hand, *SoPhy* also proved beneficial for the patients, as they got a better understanding of their therapy goals through the visualisation. The real-time visual feedback highlighted the gap between what they were doing as opposed to what they should be doing, and they were able to alter their movements to achieve their therapy goals. As such, *SoPhy* enhanced the patient's ability in trying out different exercises, which in turn, increased the treatment efficacy of the physiotherapists as treatment requires the active involvement of the patients. Overall, video consultations became more interactive with *SoPhy*, and the physiotherapists tried out different activities with the patient to conduct their detailed assessment and to recommend more appropriate treatment.

8.3. Thesis Contributions

In this section, I will discuss the four contributions made by this thesis and its implications on the existing literature in HCI and clinical domain. This thesis contributes to these fields in the following way:

1. This thesis contributes an understanding of how the physiotherapists employ bodily communication in video consultations.
2. This thesis contributes an understanding of the challenges faced by the physiotherapists in interpreting bodily information during video consultations.
3. This thesis contributes a novel wearable technology that communicates information of the patient's weight distribution patterns over-a-distance.
4. This thesis demonstrates that *SoPhy* enhances the clinical efficacy of the physiotherapists during video consultations.

Below I will discuss each contribution individually.

Contribution 1	An understanding of how the physiotherapists employ bodily communication in video consultations

This thesis generates a detailed understanding of the importance of bodily communication in physiotherapy related video consultations. Through the narration of the field studies 1 and 3, the thesis provides knowledge about how physiotherapists employ different bodily cues to assess and treat patients across different phases of a video consultation, i.e., Opening, History Taking, Examination, Diagnosis, Treatment and

Closing. A comprehensive list of different bodily cues across different consultation phases was established in Study 1 (refer Table 4-2), and was utilised later to illustrate the findings of Study 3.

These studies highlighted that physiotherapists build upon their understanding of the patient's condition as they progress from one phase to another. The presence or absence of certain bodily information in one phase influences their ability in performing the required tasks in the following phase. For instance, Study 1 highlighted that when the physiotherapists could not observe the unconscious movements of the patients in the Opening phase, they had a partial understanding of the patient's condition in the History Taking phase. This was because the exercises performed by the patients in the History Taking phase only provided information on their conscious movements, which are driven by their fear of pain and anxiety to do certain movements. Instead, the unconscious movements demonstrate the real ability of the patients in performing the tasks. This incomplete understanding of the patient's movements influenced the diagnostic confidence of the physiotherapists and made their treatment less specific. Whereas in Study 3, *SoPhy* helped the physiotherapists to gain insights of both the conscious and unconscious movements of the patients related to lower limbs. Consequently, the physiotherapists had a better understanding of the patient's recovery, which in turn, guided more specific treatment of the patients.

This structured understanding of the bodily information across different phases of a consultation is novel because such a detailed understanding is neither available in the literature on video consultations nor for face-to-face consultations of physiotherapy. For instance, although Heath (Heath, 2002, 1986) provided a foundational knowledge of bodily communication between the clinicians and patients in face-to-face consultations, this understanding is mainly related to the practice of general physician (GP) and not for the physiotherapists. On the other hand, the existing literature on video consultations only provides partial accounts of the presence and absence of different bodily information over video. The commonly discussed bodily information in the context of video consultations includes *eye gaze and eye blinks, facial expressions, head nods, body posture, spatial arrangement, tongue tremors, body movements, touch* and *smell* (refer to Section 2.3.4 in Chapter 2). Amongst these bodily cues, tongue tremors, body movements, touch, and smell are described in relation to the assessment of the patient, and the remaining were described with regards to the conversation between patients and clinicians. However, in doing so, these studies did not investigate how the absence or presence of these bodily cues influence the overall outcome of the consultation and the ability of clinicians in assessing and treating the patients.

Contrary to the existing literature, this thesis provides detailed accounts of the importance of fifteen bodily information for physiotherapists across different phases of the video consultations. This list includes (1) *facial expressions*, (2) *eye communication*,

(3) *body posture*, (4) *body movements*, (5) *quality of movements*, (6) *characteristics of movements*, (7) *spatial arrangement*, (8) *body orientation*, (9) *gestures*, (10) *touch*, (11) *tactile information*, (12) *response to touch*, (13) *pain characteristics*, (14) *vocal cues*, and (15) *appearance*. (These bodily cues are listed in Table 2-4 in Chapter 2.) By defining and describing the communication of these bodily information in physiotherapy related consultations, this thesis extends the concept of nonverbal bodily communication (Argyle, 2013; DeVito, 2011; Ekman and Friesen, 1969) from human discourse to clinical encounters between the patients and clinicians, particularly for the fulfillment of the clinical tasks related to assessment and treatment.

The generated knowledge related to the importance of bodily information and its interplay in different phases of the clinical consultations has implications to both the HCI and clinical researchers. For instance, HCI researchers can explore the potential of different technologies to support the specific needs of the physiotherapists at different times of a video consultation. Additionally, the list is applicable to explore technologies for face-to-face consultations because certain bodily information such as weight distribution, is challenging to observe even in the collocated setting. On the other hand, clinical researchers can evaluate the suitability of organising video consultations for patients with different needs. Although the mapping between bodily information and consultation phases is developed for the physiotherapy related consultations, it can also be utilised in other clinical domains relying on bodily communication e.g., rheumatology or psychiatry. Further research is required to enrich this vocabulary of bodily communication.

Contribution 2	An understanding of the challenges faced by the physiotherapists in interpreting bodily information during video consultations

This thesis developed a comprehensive understanding of the limitations of video technology in communicating different aspects of bodily information related to the patient's movements to the remote physiotherapist. While bodily communication is integral to the physiotherapy related consultations, its importance and scope were not known in the context of video consultations. In Study 1, I listed ten challenges that the physiotherapists faced throughout video consultations (refer to Table 4-3 in Chapter 4). The study revealed that the physiotherapists could not observe a wide variety of bodily cues across different phases of the video consultations, which limited their ability to assess and treat patients over video. These challenges can be categorised into three types: Firstly, the difficulty in understanding the subtle differences in the patient's movements for both the conscious and unconscious movements. The second challenge was related to the limited control on the field-of-view of the camera on the remote end, which made the patients feel awkward in doing certain activities over video. And finally, the last challenge was about involving a team of multidisciplinary clinicians together in video consultations. While Study 1 highlighted the limitations of the video technology in supporting bodily communication, Study 3 illustrated how the use of a novel wearable technology, *SoPhy* can resolve these challenges (refer to Table 7-4 in Chapter 7). Below I will describe whether and how the challenges related to these three categories were resolved in Study 3, and what are the implications of these challenges to the HCI literature.

Study 3 revealed that *SoPhy* resolved the challenges related to mediating the subtle differences of the patient's movements over video (first category mentioned above). By providing key information related to the lower limb movements (i.e., weight distribution, foot orientation and range of movement), *SoPhy* enhanced the efficacy of the physiotherapists in assessing and treating patients over video. The need to understand the subtle differences in the movements is not only critical in 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., 2012b), and respiratory physiotherapists[21] deal with the acuity of the patient's breathing patterns to diagnose lungs infection. Owing to the importance of the subtle details in clinical consultations, I add *Subtlety* to the list of five key aspects that Olson and Olson (Olson and Olson, 2000) defined as important to support rich video-mediated communication. This list includes visibility (visible to each other), audibility (speech), contemporality (real-time message delivery), simultaneity (both ends can send and receive information), and sequentiality (turn-taking). While the list was described for non-clinical setting, adding *Subtlety* makes the list applicable to the clinical setting. *Subtlety* refers to the fine-grained differences in the patient's bodily information that illustrates the underlying health issue, and are therefore essential for the clinicians to conduct assessment and treatment. However, *subtlety* of the bodily information cannot be solely supported by the video technology, as the audio and video streams in a video call are typically adulterated (Mentis et al., 2016a). Sensing technologies will therefore, be required to support *subtlety* in video consultations, as I demonstrated in Study 3.

On the other hand, the challenge related to the patient's awkwardness was not observed in Study 3. It was because in Study 3, the patients mainly performed standing exercises as their rehabilitation was focused on normalising their weight bearing patterns. Awkwardness will be an issue with certain types of exercises, e.g., when the patient is required to lie down on the bed or on the floor, as was seen in Study 1. The awkwardness over video resonates with the existing literature on video-mediated communication in a non-clinical setting, where the ambiguity of eye gaze of the remote person can potentially make the other person feel awkward (Obata and Sasaki, 1998; Sellen, 1995). As such, there are more possibilities of having such awkward moments in

[21] Chest Physiotherapy https://physioworks.com.au/treatments-1/chest-physiotherapy

physiotherapy consultations because patients generally demonstrate different exercises by standing away from the screen to provide a full body view to the remote physiotherapist. Being away from the screen limits their understanding of how they are visible to the remote physiotherapist, i.e., their field-of-view. Hence, the underlying technology should provide more control to the patients so that they can adjust their field-of-view from a distance. For example, when the patient moves away from the screen, feedback on the field-of-view could be provided on their mobile phone - similar arrangement was explored by Meixner and colleagues to support home rehabilitation of the patients (Meixner et al., 2016).

Finally, the challenge related to involving the whole team of multidisciplinary clinicians together in video consultations was not resolved in Study 3. In fact, this challenge changed the course of the study from the defined protocol, e.g., the third session with a patient (Paige) was organised in the face-to-face setting instead of a video consultation (as defined in the protocol) to allow assessment by the whole team. This challenge can be understood by the concept of *coupling in work*, described by (Olson and Olson, 2000). Coupling refers to the extent of interdependency between different components of work. Because of the specific nature of the underlying work between remote ends, coupling in a clinical setting is different. For instance, the focus of communication in a non-clinical setting is to support the collaboration of tasks between remote ends, where both ends actively participate in the fulfillment of the task at hand. However, the focus of video consultations is on pursuing *collaborative care* of the patients, where both the clinicians and patients collectively work to manage or cure the patient's condition. Instead of co-participation, clinicians are responsible to observe and gather an understanding of the patient's condition. To this end, in a clinical setting, the task i.e., the patient body is at the remote end and the collocated clinicians attempt to work on it.

In Study 1 & 3, coupling in work existed among multiple clinicians present in the collocated setting, as all of them were focusing on understanding the patient's condition over video. In both the studies, only those consultations were organised over the video where the coupling of tasks amongst different clinicians was loose. For instance, in Study 1, the consultations were organised by the physiotherapists and other clinicians such as the pain consultant and occupational therapist briefly appeared in the consultation either at the beginning or towards the end. Previous works have explored the coupling of tasks between remote clinicians. As an example, Mentis and colleagues (Mentis et al., 2016a) demonstrated how to successfully support shared decision-making between remote surgeons during an organ transplantation surgery. Although the degree of coupling is not described it can be considered between moderate to tight coupling as one surgeon was conducting the operation, and another surgeon was helping in taking critical decisions in real-time. This research puts forward a new case for future investigation, where the coupling of work existed among the collocated clinicians working together on a patient's case during video consultations. Supporting multidisciplinary clinicians is important because a large number of chronic conditions involve multiple experts (Zhu and Cahan, 2016), and because these conditions require long-term management, they are more suitable for video consultations (Australian Physiotherapy Association, 2014).

Contribution 3	A novel wearable technology that communicates information of the patient's weight distribution patterns over-a-distance

The third contribution is offered through the development of a wearable technology, *SoPhy*, which monitors lower limb movements of the patients during video consultations. *SoPhy* captures information related to weight distribution, foot orientation and range of movement when the patient performs lower limb exercises wearing the *SoPhy* socks, and presents the information to the physiotherapist in real-time. Study 2 & 3 showed that physiotherapists particularly appreciated the information related to weight distribution as offered by the *SoPhy* visualisation. Also, the information on weight distribution was sufficient to understand the patient's foot orientation patterns. Understanding the weight distribution patterns of the patients are challenging for the physiotherapists not only over the video but also in the face-to-face setting because the pressure points are not visible. As found in Study 2, physiotherapists assess weight distribution patterns of the patients through other bodily cues, such as the sound of hitting the ground or the posture of lower limbs from hip to the feet. However, these signals do not provide information of whether the patient is bearing the weight on the outside, inside or at the back of the foot - which *SoPhy* offered. Since *SoPhy* visualisation made the invisible data of weight distribution patterns visible, the physiotherapists appreciated the presented information both in video and face-to-face consultations in Study 3.

Visualisation of the weight distribution patterns is a novel contribution because the existing systems for physiotherapy mainly highlight the importance of the range of movements to recover functioning of the affected body part. For instance, Physio@Home (Tang et al., 2015) and RVS (Ayoade and Baillie, 2014) respectively monitor and visualise information of the range of movement to support arm and knee rehabilitation (refer to Table 2-5 & 2-6 in Section 2.4.2 for a summary of the existing systems). This research, however, highlighted that range of movement is not as critical as weight distribution for lower limb rehabilitation. On the other hand, commercially available systems like Nintendo Wii-Fit or Sensoria socks also provide information of weight distribution. These systems are, however designed to support the patients at home. For instance, Nintendo Wii-Fit utilises information of the patient's weight-bearing patterns as a game input, whereas Sensoria socks aim to support awareness of full body balance for everyday activities like walking and running. To this end, there was no study that illustrated how and why the information of the patient's weight distribution patterns are critical for the physiotherapists - an understanding that this thesis offered.

SoPhy was successful because it supported the physiotherapist in having the knowledge of three media spaces: *people, task,* and *reference space* proposed by (Buxton, 2009). Buxton (ibid.) suggested that these three media spaces should be mediated to support collaboration during video conferencing in a non-clinical setting. In a physiotherapy related video consultation, person and reference spaces are the same i.e., the patient's body - because all the conversation and communication happens around the patient's body (Dillman and Tang, 2015). On the other hand, the task space can be referred to as the Movement space - the space where the patient performs the movements. Movement space is important because it is only through this space, that the physiotherapists can understand the patient's movements. While understanding the movement space is easier for the physiotherapists in a face-to-face setting, it is challenging in video consultations. For instance, in face-to-face consultations, by being present in the same three-dimensional space with the patient, the physiotherapists can understand the movement space in relation to their body. This is because our understanding of the space is always relative to our tasks, and our senses recognise it in relation to our bodies (Presson and Montello, 1994). On the other hand, during video consultations, being present in different spaces and seeing the patient's movement space in the form of pixels on a 2D screen, limits the physiotherapists in understanding the patient's movements. For instance, details of lower limb movements such as weight distribution, the range of movement and foot orientation are understood through the patient's movements on the floor. Since *SoPhy* visualised the movement space (i.e, floor) of the patient on a screen, it became easy for the physiotherapists to understand the patient's lower limb movements.

Contribution 4	Demonstrated that *SoPhy* enhances the clinical efficacy of the physiotherapists during video consultations

This thesis demonstrates that the clinical efficacy of the physiotherapists during video consultations can be enhanced by designing sensing technologies like *SoPhy*. Study 2 & 3 highlighted that *SoPhy* offered key aspects of the lower limb movements (i.e., weight distribution, the range of movement and foot orientation) that the physiotherapists need to assess the patient's recovery. Having access to the essential bodily information offered early confirmation to the physiotherapists on their assessment, and boosted their confidence in assessing different exercises over video. In Study 3, the increased confidence in assessment guided more specific treatment of the patients, where the physiotherapist was able to appropriate the therapy around the current condition of the patients. Study 3 also demonstrated that *SoPhy* enriched the interactions between the patient and physiotherapist, as it offered a common language to discuss the patient's movements. As such, the video consultations became more interactive with *SoPhy*, and the physiotherapist was able to better understand the patient's condition throughout the session. All these factors lay the foundation of a stronger clinician-patient relationship, as emphasized in the existing literature (Demiris et al., 2010; Storni, 2009).

Enhancing the efficacy of video consultations is a novel contribution because research on video consultations has majorly been limited to evaluating the feasibility of video technology to consult different clinical issues (Demiris et al., 2010; Dorsey and Topol, 2016; Ekeland et al., 2010; Miller, 2011, 2003). While several researchers have highlighted the limitations of video technology in supporting different tasks of the clinicians (Demiris et al., 2010; Dorsey and Topol, 2016; Miller, 2011), little attempts were made to support and enhance their abilities. To this end, this research is one of the first attempts made to support the needs of clinicians during video consultations. Previously, Stevenson (Stevenson, 2010) investigated a different setup of video consultations and utilised multiple webcams and a pen-and-tablet system to enhance the communication between the patient and surgeon over video. However, the author focused on supporting the specific needs of surgeons and not the physiotherapists. In the context of physiotherapy, the technological advancements have been either limited to the laboratory evaluation with healthy people, or to supporting patients at home (refer to the review of technologies in Section 2.4.2). To this end, Study 3 is the first study, where a prototype system is evaluated through field deployments in the hospital setting in the context of physiotherapy video consultations.

In Study 2 and 3, the evaluation of *SoPhy* was guided by a model that was developed by combining an existing efficacy model for evaluating new imaging systems (Fryback and Thornbury, 1991) and six phases of clinical consultations (Byrne and Long, 1976). Details of the model are provided in Section 2.2.5. The model was developed because the existing literature on video consultations lacked in defining specific measures or models that can be utilised to evaluate the impact of new technologies on meeting the goals of a video consultation. Since the model takes into account three actors of video consultations: patient, clinician, and technology, it allowed rigorous evaluation of *SoPhy* around critical aspects of the consultation in Study 2 & 3 both. In this regard, the model presented in Table 2-2 is a novel contribution to the literature on video consultations. Although the model was developed for physiotherapy related consultations, it can easily be utilised to evaluate the influence of new video consultation systems for different clinical domains. However, in order to do so, the model requires certain appropriations, e.g., the parameters across each aspect (as described in Table 2-1) need to be redefined around the clinician-patient activities for the given domain.

8.4. Limitations & Challenges

This section highlights the limitations of this work with respect to the methodological challenges of conducting research in the context of video consultations. Blandford and Berndt (Blandford and Berndt, 2010) described that conducting research in the clinical domain by non-medical personnel is always challenging. These challenges shape the overall conduct of the research and therefore, should be mentioned to guide future research as well as to ensure the quality of research. I will describe the limitations of this work around the four criteria of credibility, transferability, dependability, and confirmability (Lincoln and Guba, 1985), that was described in Chapter 3 to evaluate the quality of field research (refer Section 3.3.3 for details on the evaluation criteria). This research has at least the following three limitations:

8.4.1. Limited Credibility of the Data Collected through Observations

The first limitation is about the credibility of the data collected through participant observations in the field studies. Collecting multimedia data such as video and audio recording is essential for researchers to get a rich understanding of the context. However, the data collection in Study 1 & 3 was limited mainly to observations and interviews. The decision for data collection resources was inspired by the sensitivity of the setting, and the multi-site nature of the video consultations that required flexibility in the data collection. For instance, video consultations involve communication between at least two remote sites, with each site having multiple people. Also, video consultations are often organised in different locations, such as a regional clinic or the patient's home, depending upon the needs of the patients. To this end, having observations as the main resource for data collection reduced the efforts required from the patients to participate in the study, and kept the consultations natural. Additionally, it also reduced the concerns of managing the patient's data collected from the study, which other multimedia recordings would have raised, e.g., storage of videos is always a big concern for the hospital staff. Consequently, having observations as the main source of data collection made the clinical staff and the hospital ethics committee relaxed with the conduct of this research.

While observations provided a relaxed and simple approach to collect data, it also raised the concern of credibility of data collection because observational notes can be erroneous. For instance, I may have missed out certain key events of the session or have misinterpreted certain events while taking notes, with no opportunities to correct them afterwards. This is a significant issue given that the focus of this research was to understand the bodily communication during video consultations. Since bodily signals are non-verbal and are specific to the context, interpreting these signals also involve significant subjectivity of the interpreter (Argyle, 2013; DeVito, 2011) - thus increasing the chances of collecting erroneous data. However, I applied different approaches to ensure the accuracy of the collected data. Firstly, employing Member checking technique (Lincoln and Guba, 1985), I validated the collected data with the collaborating physiotherapists to get their feedback on my interpretation of the data. Secondly, I paid more attention to develop and revise the observation guide for the study. These revisions were made in consultation with my supervisors to avoid any assumptions or biases, as well as to narrow down data collection only around the study aims. Finally, I have provided a detailed account on the data collection process both in the chapters and in the respective appendices to make the process transparent and auditable.

8.4.2. Limited Transferability of SoPhy to Other Clinical Practise

Another limitation is related to the transferability of *SoPhy* to the clinical practise of other physiotherapists. *SoPhy* was designed by considering the clinical practice of the physiotherapists from the collaborating hospital. I mainly worked with one physiotherapist, where the development was guided by his clinical practice and evaluated with him in Study 3. On the other hand, some design decisions were taken to satisfy the protocols of the collaborating hospital. For instance, the choice of displaying the *SoPhy* visualisation on a separate screen was inspired by the setup of video consultations followed at the hospital. The hospital staff utilises two screens to organise video consultations: one for making the video call and another for referring to the patient's records. Dedicating a separate screen to patient's video stream mainly ensure a good view of the patient throughout the video session, and does not require any management by the clinicians (e.g., arranging different software on the same screen). Following this practice, I also displayed the *SoPhy* visualisation on a separate screen, instead of having a big screen displaying both the video call and the visualisation. Following the same arrangement required little efforts from the hospital staff and made the field deployments easier.

In this regard, *SoPhy* may not be directly applicable to other physiotherapists and other hospitals organising video consultations, which raises the concern of transferability of *SoPhy*. Following the suggestion of Lincoln and Guba (Lincoln and Guba, 1985), transferability could have been achieved by testing the system with physiotherapists working at other hospitals. However, it was not feasible given the limited duration of my PhD candidature. For instance, establishing collaborations with a new hospital and motivating clinicians in using new technologies that are not designed with them are bigger issues, which are also iterated by other HCI researchers (Blandford et al., 2015; Furniss et al., 2014). Clinicians are careful about bringing new technologies in the consultations, as it may have an adverse effect on their relationship with the patients (ibid.). Hence, I evaluated the prototype with the same physiotherapists who participated in the study as they were already aware of the research and were motivated to participate. Both the physiotherapists were confident about the potential applications of *SoPhy*, and therefore they were motivated to convince their clients to participate in the study. Participation in Study 3 was tricky because it required patients to meet their physiotherapist over video and not in a face-to-face setting, even though they were already at the hospital.

However, I attempted to support transferability of *SoPhy* to other settings. In this regard, I have provided a detailed account of how the design decisions were taken in Chapter 5. This detailed account will help in appropriating the design and working of *SoPhy* for different contexts. Additionally, the laboratory evaluation of *SoPhy* in Study 2 with the postgraduate physiotherapy students demonstrated that the system is applicable to the clinical practice of other physiotherapists.

8.4.3. Limited Transferability of the Study Findings to Other Clinical Contexts

The final limitation is about the transferability of the findings collected from the field studies (Study 1 & 3), as both the studies were conducted with a limited number of patients and physiotherapists. The limited number of participants was a bigger issue in Study 3 because the study aimed at demonstrating the influence of *SoPhy* on the clinical practice of physiotherapists. Demonstrating the efficacy of *SoPhy* with one physiotherapist and three patients raises concerns related to the applicability of the study findings to assess and treat patients with lower limb issues, in general. However, the limited number of participants in these studies was guided by several factors. Firstly, the data collection was limited to only two physiotherapists because they were the only physiotherapists at the collaborating department of the hospital. While both the physiotherapists participated in the first study, the majority of the research was conducted with mainly one physiotherapist. This is partially because clinicians follow a busy schedule and may not always have potential clients. But more than that there is an inherent challenge of motivating clinicians to a research project initiated by external organisations. Moreover, video consultation is relatively a new practice, and hence most clinicians do not organise regular video consultations. The reason being that adopting video consultations require clinicians to go through a structured training, where they can learn about using technology to organize consultations - which is not always feasible given their busy schedule.

On the other hand, the studies were conducted with a limited number of patients because many of the patients were vulnerable to introducing to new people and to new technologies. Hence, the physiotherapists did not invite them to participate in the study.

Additionally, the consultations are structured around the patient needs. Thus, the consultation frequency for each patient can vary from weekly to several months - which reduced the number of sessions possible in a given time frame. Finally, Study 3 followed a specific recruitment criterion and required participation from patients having lower limb issues. Since there is no specific quota of patients at a given period, having a significant number of patients with lower limb issues during the study period was challenging. For instance, over a 5-month period, only one physiotherapist had three clients who were suitable for participating in the study.

However, I strove to obtain transferability with the data collected in both the studies. For instance, in Study 1, I utilised the structure of phases to develop a detailed understanding of the clinician-patient interactions during video consultations. On the other hand, in Study 3, I developed an efficacy model that allowed me to rigorously evaluate the influence of *SoPhy* on different aspects of a consultation, e.g., assessment, treatment, clinician-patient communication. Besides, I have also provided a detailed account of the data collection and data analysis in the respective chapters as well as in the appendices to make the research process transparent and auditable.

8.5. Opportunities for Future Research

Based on the insights gained through the research conducted across different phases of this thesis, below I discuss opportunities for future research to advance our understanding of video consultations and to harness its full potential.

8.5.1. Making Video Consultations Effective for Patients

This work explored video consultations from the clinician's perspective and designed a technology to support the tasks of physiotherapists during video consultations. Future research is required to understand the experience of the patients in video consultations, e.g., what challenges they face in understanding the bodily information of clinicians, how does video consultation influence their participation and responsibilities, and how can we better support the treatment of patients over video. As discussed in Chapter 7, a collective reflection on the patient's recovery and therapy goals are key elements of consultations that require an active involvement of patients in the consultations. Although *SoPhy* became a useful tool to discuss the patient's goals, the visualisation needs to be further developed to support patients. For instance, the visualisation should explicitly highlight the patient's achievement through scoring boards or through different visualisations, to provide them greater motivation for maintaining their exercise routine.

Understanding the patient's perspective is important because clinical consultations follow *institutional asymmetry* of role (ten Have, 1991), where the clinicians leverage higher authority than the patients. This was also evident in the field studies 1 & 3, where the patients did not make any request to their physiotherapist to rearrange the camera or to repeat an exercise to better understand the required movements. They simply followed the instructions but hesitated to make such requests when the clinicians demonstrated new exercises. Study 1 also revealed that the patients struggled in getting higher mobility with the underlying technology which in turn, raised awkwardness of performing certain exercises in video consultations. Therefore, future research is required to understand how patients interpret the clinician's bodily information in video consultations and how can technology better enable the patients to discuss their concerns with the clinicians. For instance, physiotherapists can wear *SoPhy* socks to help the patient in understanding the correct movements, or to train them regarding how much weight they should bear on the affected foot.

8.5.2. Involving Multiple Co-Located Clinicians in Video Consultations

In this thesis, I focused on enhancing the interactions between the patient and physiotherapist in video consultations by supporting the essential bodily information required for assessment and treatment. However, this thesis revealed another setup of video consultations, where multidisciplinary clinicians were present at the clinician end to offer consultation to the remote patient. As studies 1 & 3 were conducted in the pain management department, the consultations involved a team of multidisciplinary clinicians (e.g., a physiotherapist, occupational therapist, psychiatrist, psychologist, and pain consultant) to treat chronic pain patients. In these consultations, each clinician was focussing on the specific aspect of the patient's condition, e.g., physical health of the patient was managed by a physiotherapist and mental health by a psychiatrist. In both the studies, I found that involving the entire multidisciplinary team together in a video consultation was challenging. Consequently, each clinician either organised a separate video consultation with the patient, which limited the opportunity to formulate a collective assessment of the patient. Or in other cases, they organised a face-to-face consultation to allow the team to assess the patient's progress.

Previously, several researchers have investigated different settings of video consultations with multiple clinicians involved. Examples include the consultation between a clinician and a patient when the patient is accompanied by a nurse or surgeon (Stevenson, 2010) and between remote surgeons to support surgery of organ transplantation (Mentis et al., 2016a). On the other hand, Bardram and colleagues, in a great deal, investigated the dynamics of collaborative tasks of the clinical staff in the hospital setting (Bardram, 1998, 2000; Bardram and Doryab, 2011; Bardram and Hansen, 2010). Much can be learned from these works to investigate ways to support a team of multiple collocated clinical experts when a video consultation is organised for a remote patient. Also, although the challenge emerged from the context of chronic pain patients, such collaborations between multidisciplinary team of clinicians is required for other health conditions as well, such as Dementia or post-surgery rehabilitation.

The key point here is to design systems that can effectively support the needs of different experts at the same time in video consultations. To understand this aspect of video consultations, *Locales framework* (Kaplan and Fitzpatrick, 1997) could serve as a starting point. The different aspects of the framework will help to understand the needs of different clinicians and to come up with a design that best supports the interactions between their tasks and requirements. For example, while the psychiatrist would need bodily information of how the patient is talking and sitting to understand the mental and emotional wellbeing, occupational therapist requires details of daily activities of the patient (*individuality*). On the other hand, all clinicians talk to each other either in front of the patient or in private to formulate a collective assessment (*mutuality*). Since all the clinicians are focusing on different aspects, each clinician may require a specific system like *SoPhy* apart from the video connection to enhance their understanding of the patient during a video consultation. This raises many interesting questions, such as how does the competence of different clinicians come into the picture (Larsen and Bardram, 2008); how will we define the coupling between different tasks (Olson and Olson, 2000); and what will be the spatial arrangement of the artefacts and people in the room (Hall, 1966; Kendon, 2010).

8.5.3. Extending Video Consultations to Asynchronous Consultations

To date, video consultations are explored to support synchronous communication between the patients and clinicians. While synchronous communication is good, video consultations can also be extended to include asynchronous form of communication. In the asynchronous form of video consultations, the interactions between the patients and clinicians do not happen in real-time rather happen in ad-hoc manner based on their availability. Asynchronous video mediated communication has been around to support video messaging for interpersonal communication, where platforms Skype Qik[22] and Peeq[23] allow people to create and send short video messages to their friends. These short video messages were described as gifts that participants exchanged with their loved ones to express their emotions and friendship (Raffle et al., 2011; Rintel et al., 2016).

In clinical consultations, there is a bigger role of asynchronous interactions, something that is not explored in the literature. Firstly, asynchronous consultations will support timely reflection on the patient's condition and recovery, which in turn will enhance the

[22] Skype Qik. https://en.wikipedia.org/wiki/Skype_Qik
[23] Peeq app. https://www.peeqdata.com/

clinician-patient relationship and will support patient-centred care (Wilcox et al., 2013). Having the right feedback at the right time is defined as a crucial aspect in the goal-setting theory to improve self-efficacy of the patients and to keep them motivated (Winstein et al., 1994). For instance, patients can send short videos of their exercises to the physiotherapists, and the clinicians can annotate the video to provide feedback to the patients - similar to the system proposed by Li and Alem (Li and Alem, 2013). Such a feedback will help the patients to correct their movements on time and would prevent improper training of muscles through incorrect movements. Furthermore, asynchronous consultations will open another interesting venue of the *active patients*, where the patient is actively involved in taking care of their health issue. The concept of *active patient* is already shaping up with the penetration of quantified-self technologies in everyday life, as users are taking keen interest in logging their daily life and reflecting on the patterns to take necessary steps (Appelboom et al., 2014; Rajabiyazdi et al., 2017; West et al., 2016).

Asynchronous video consultations, on the other hand, will also bring several challenges to clinical practice, and hence require in-depth exploration. Firstly, it raises a concern of increasing the clinician's workload in responding to the patient's messages. Additionally, it would also require new guidelines and protocol on how and when to check these messages, and how to reply to these messages, e.g., would clinicians need to make a video recording of themselves to demonstrate the correct exercise, or would they want to annotate the video recording of the patient to describe the necessary steps. Clinicians would also require adequate training in order to adapt to such emerging forms of communication. Additionally, how the created videos will be sent and stored such that the patient's privacy is maintained, is another significant concern. Nevertheless, a flexible platform supporting the needs of the clinicians and patients may effectively extend video consultations to asynchronous clinician-patient interactions.

8.5.4. Extending the Use of SoPhy in Face-to-Face Consultations

Although face-to-face consultations are considered effective in terms of assessment and treatment of the patients, understanding subtle differences in the patient's movements is challenging even in the face-to-face setting. In Study 2 and 3, the physiotherapists were keen to use *SoPhy* in face-to-face consultations particularly to understand the weight-bearing patterns of the patients as they are difficult to eyeball. In Study 3, *SoPhy* corrected the assessment of the physiotherapists in both the face-to-face and video consultations. Not only for the physiotherapists, the *SoPhy* visualisation also helped the patients in reflecting upon what they were doing as opposed to what they should be doing. Hence, there is a significant potential for using *SoPhy* in face-to-face consultations. Mentis and colleagues (Mentis et al., 2016b) also emphasized the difficulty in interpreting patient's bodily information in a face-to-face setting particularly for movement-related disorders. They described the subjectivity associated with interpreting bodily information and described that our life experiences affect our ability to "see" and communicate bodily information. Further investigation is therefore, required to support the physiotherapists in understanding the patient's bodily information during face-to-face consultations.

Apart from the physiotherapy domain, *SoPhy* can also be utilised to assess and treat lower limb issues for a variety of other clinical domains relying on the bodily information. Some examples include sports rehabilitation, Orthopaedics, and Geriatric conditions. Additionally, *SoPhy* can be used as a training tool to teach patients on how to walk with amputees (artificial legs) or how to use crutches after an injury, where the visual feedback will help the patients to understand how much weight they should be bearing on the affected foot. As the *SoPhy* socks afford mobility, it provides flexibility to the clinicians and patients to try out different types of exercises under the different environment (e.g., stairs and gymnasium) - which aligns with the overall goal of the rehabilitation program of the patient. However, as discussed in the limitations section earlier, *SoPhy* would require some appropriations in its design to suit the requirements of the given context.

8.5.5. Extending the Applications of SoPhy for Home Rehabilitation

SoPhy can be further extended to support rehabilitation of the patients, at home either in between the consultations or post rehabilitation program to help them remain active. As found in Study 3, the patients were willing to continue using *SoPhy* at home to practise the recommended exercises. Patients found the subtle differences highlighted by the visualisation helpful as they were no longer required to rely on their proprioception to understand the differences in their movements. Technologies to support patient at home have been successful in the past as the patients need motivation and right feedback to drive their own recovery (refer Section 2.4.2 for more details on the existing systems for home rehabilitation).

However, *SoPhy* would need further development to support such usage. For instance, the current *SoPhy* visualisation presents the movement data on a web-interface without highlighting whether the performed movement by the patient is correct or not, and how can the patient improve their movements for a certain exercise. Different strategies can be applied to extend the *SoPhy* visualisation for home applications. For example, instead of the visual feedback, the system can provide audio feedback to the patients on their movements - similar to the system developed by Singh and colleagues (Singh et al., 2016). Given the higher mobility of audio feedback, such a feedback mechanism will support real-time reflection on a wide range of everyday activities of the patients, e.g., cooking and doing laundry. With further extension, *SoPhy* can provide critical and timely feedback on the patient's movements and can help them to correct their movements, when performing the exercises in the absence of their physiotherapists.

8.6. Concluding Remarks

This thesis investigated how interactive technologies can support the physiotherapists in understanding the patient's bodily information during video consultations. To address this question, I conducted three studies each employing a different methodology. Study 1 utilised the field research approach, which was followed by a development phase to design a research prototype, *SoPhy*. Study 2 and 3 evaluated the efficacy of *SoPhy* to support the tasks of physiotherapists through laboratory and field evaluations. Through the conduct of these three studies, this thesis makes four contributions. Firstly, it generates a detailed understanding of how physiotherapists employ bodily communication at different phases of video consultations in order to assess and treat patients. Secondly, the thesis developed an understanding of the challenges faced by the physiotherapists in understanding the patient's bodily information during video consultations. The third contribution is related to a novel technology that communicates information about the patient's weight distribution patterns over-a-distance, to support the tasks of the physiotherapists. And finally, the thesis demonstrated that the clinical efficacy of the physiotherapists can be enhanced during video consultations by using sensing technologies like *SoPhy*.

This research has implications to the literature in both the clinical and HCI domains. It demonstrates that limiting video consultations to the audio-visual medium will not be sufficient particularly for clinical domains that rely on bodily information for the patient's recovery. In fact, other sensing technologies are required to mediate bodily information over-a-distance for the effective assessment and treatment of the patient. Consequently, it is crucial to carefully design and install technologies that can support the clinician-patient interactions remotely. Also, understanding the effectiveness of the video technology for a clinical domain requires knowledge from both the clinical and HCI domains. In this regard, research in this area not only requires a combination of the skill sets from both the domains, but also the knowledge of different methods and theoretical concepts. Such an intersection of these fields will generate a detailed understanding of the clinician-patient interactions during video consultations for the given clinical domain and will guide further proliferation of video consultations.

We however, need a different perspective to understand the potential of video consultations. As both the video and face-to-face consultations are organised in different mediums, they both offer different benefits and potential. Therefore, rather than seeing video consultations as a replacement for the face-to-face consultations and making video consultations similar to the face-to-face consultations, there is a need to explore a different application space for the video consultations. The key point here is to investigate what video-based interactions offer to the patients and clinicians, which is either challenging or not possible to perform in the face-to-face settings. For instance, even though physical interactions are not feasible during video consultations, the possibility of connecting the patients with their clinicians in situations when face-to-face consultations are not possible will certainly support stronger patient-clinician relationship.

Video consultations follow the true essence of the patient-centered care, where the clinician tries to enter into the patient's world to understand their health issue. In fact, it replicates the standard clinical care practice, where clinicians make home visits to examine patients. As such, video consultations allow the clinicians to understand the patient's living conditions, which they can utilise to alter the treatment. This is particularly important for patients undergoing rehabilitation, as the aim of rehabilitation is to enable the patients to perform daily mundane activities. This research highlighted different future directions to further investigate the potential of video consultations. I hope this research will inspire exploration of new video consultations systems that can effectively support the clinician-patient interactions for a given context.

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Appendix A
Material for Study 1

Overview: This Appendix provides additional documents on data collection and analysis process of Study 1 in order to make the research process transparent and auditable. The listed documents were referred to in Chapter 4 of this thesis. The Appendix contains the following documents:

A.1 presents the plain language description of the project provided to participants

A.2 shows the pain recording tool used at the hospital

A.3 presents an example of the daily log maintained by patients

A.4 presents the observation guide that was used to conduct participant observations

A.5 illustrates the process of developing field notes

A.6 presents examples of writing down informal conversations as field notes

A.7 shows the guide utilised to interview the clinicians and patients

A.8 presents an example of summarising interviews as handwritten notes

A.9 describes the process of analysing the study data

A.1. Plain Language Description for Clinicians

The following document provides the plain language description of the project that was provided to participants in the study. As participants for Study 1 were clinicians, patients and their carers, I developed three plain language statements of the project. These documents were part of the ethics application approved by the Ethics Advisory Group at the Royal Children's Hospital. The hospital ethics refer plain language description of the project as information letter. This document was referred to in this thesis in Section 4.2. Below I present the clinician's information letter.

THE UNIVERSITY OF MELBOURNE

The Royal Children's Hospital Melbourne

INFORMATION LETTER

HREC Project Number: 35112A

Project Title: Understanding the user experiences of teleconsultation sessions

Investigators: Deepti Aggarwal, Dr. Bernd Ploderer, A/Prof. Frank Vetere and Susan Jury

Dear Clinician,

What is the research project about?
The purpose of this study is to investigate the user experience of using teleconsultation systems. By teleconsultation, we mean a video consultation between a patient and clinician for diagnostic or medical advice. The aim of this study is to understand how teleconsultations happen, what technology is used, and what technology challenges are faced. This study will be valuable for designing future technology for teleconsultation sessions.

This project will form a part of Deepti Aggarwal's PhD research, and has been approved by the Human Research Ethics Committee (HREC) at the Royal Children's Hospital.

Who is funding this research project?

Funding for this project will come through the student researcher's PhD scholarship from the University of Melbourne.

Why am I being asked to be in this research project?
We are looking for people who are involved in a teleconsultation or face-to-face consultation as a patient, clinician, or carer. We would like to invite you to participate in the study because you provide health care support to patients using teleconsultation systems. The information you provide will provide us insights on the abilities and limitations of the current teleconsultation systems.

What does participation in this research involve?
This study has two parts: **observation** of a consultation session (teleconsultation or face-to-face consultation) and an **interview**. You can choose to participate in either one or both parts of the study.

If you choose to participate in the **observation**, a researcher will sit with you in your consultation session. We will take notes on the communication and interactions that happen during a medical consultation between you and your patients. In this regard, we will not include specific medical information in our notes. Notes about medical information will only be taken in general terms to convey how such information is communicated, for instance, through technology (e.g., laptop) or other artefacts (e.g., paper based forms). We may also take photographs of the setup (without any people) before or after the consultation to record the arrangement and setup of technology in this context. Observations will happen at your place. It does not require any activity from your side.

We would also like to conduct **an interview** with you afterwards to reflect upon your overall perception about the role of technology in supporting medical consultation. This interview will be at a time and place convenient for you, or via telephone or video chat. The interview will last for approximately 20-30 minutes. We would like to make an audio recording of our conversations. This helps us to study the discussion in detail.

Finally, we also seek your support to **assist with the recruitment** of participants for this study. We would like to request your support to recruit patients and their carers whose consultations would be appropriate for observations by the student researcher. Additionally, we may also ask you for your support to recruit other clinicians at RCH who offer teleconsultations and would be interested to participate in this study.

What are my alternatives to taking part?
Your participation in this study is completely voluntary. If you do not take part, or choose to withdraw from the project, it will not affect your employment at The Royal Children's Hospital.

You are free to withdraw from the project at any time without telling us why. If you withdraw, we would like to use any information that we have already collected after seeking your permission.

What are the potential benefits for me and other people in the future?
You will have an opportunity to reflect on your experiences with the teleconsultation systems, which may help you to vent possible frustration with current systems and to develop greater skills. Some participants may appreciate an opportunity to have a voice

in improving the services and technologies that they are using. Furthermore, you will assist us in designing future teleconsultation systems.

What are the possible risks, side effects, discomforts, and/or inconveniences?
We don't expect that this study introduce any risks. However, we do understand that having a researcher sitting in the consultation or discussing the concerned medical information could make you feel uncomfortable. Please feel free to ask the researcher to leave the room at any time to discuss private information with your patient. Likewise, we have done our best to make sure that the interview questions do not cause you any distress. However, you are free not to answer the question if you feel uncomfortable.

If we ask questions regarding your interaction with the technology, our aim is to evaluate the strengths and weaknesses of the technology and not to judge your technical knowledge. If the researcher observes or discusses the session's medical information, we want to assure you that we will not record specifics of this information. Medical information will only be recorded in general terms to convey how such information is communicated through technology in line with the research aim of understanding how technology is used to communicate over a distance.

What will be done to make sure my information is confidential?
All the information collected will be stored securely in the Department of Computing and Information Systems at the University of Melbourne for 7 years after the youngest participant turns 18 years of age. After this time, we will destroy it. All the electronic files will be password protected and kept on computers in the secured offices to which only members of the research team and the RCH ethics committee will have access. In accordance with relevant Australian and/or Victorian privacy and other relevant laws, you have the right to access and correct the information we collect and store about your child. Please contact us if you would like to access this information.

The stored information will be re-identifiable. This means that we will remove identifying information such as your name and give the information a special code number. Only the research team can match your name to the respective code number, if it is necessary to do so. Personal information apart from the age and gender will not be revealed. At the end of the study, results may be presented at conferences or published in medical journals. In all such cases, we will use a pseudonym if we need to refer you.

Will I be informed of the results when the research project is finished?
At the end of the project, we will send you a summary of the project's results, if you provide your mail address on the consent form. Please be mindful that the findings will be an indicative of the whole group of participants and not of every individual.

The full report of this study results will be disseminated through peer-reviewed publications and conference presentations across the research communities in health, and technology.

From where can I get further Information?
Should you require any further information, or have any concerns, please do not hesitate to contact any of the following people:

- Deepti Aggarwal (daggarwal@student.unimelb.edu.au, 0 47007 3052)
- Dr. Bernd Ploderer (ploderer@unimelb.edu.au, 03 8344 1511)
- Assoc. Prof. Frank Vetere (f.vetere@unimelb.edu.au, 03 8344 1496)

- Susan Jury (susan.jury@rch.org.au , 03 9345 4645)

How do I agree to participate?

We hope that you will take part. If you would like to be a part of the research project, please read and sign the attached Consent Form. Please return the signed Consent Form to Deepti Aggarwal via email (daggarwal@student.unimelb.edu.au) or as hard copy. You may keep a copy of the Information Letter and Consent Form for your reference.

Thank you for your help.

Yours sincerely,

Deepti Aggarwal
PhD Candidate
Dept. of Computing and Information Systems
The University of Melbourne

Bernd Ploderer
Lecturer
Dept. of Computing and Information Systems
The University of Melbourne

Frank Vetere
Associate Professor
Dept. of Computing and Information Systems
The University of Melbourne

Susan Jury
Manager
Telehealth Services
Royal Children's Hospital, Melbourne

If you have any concerns about the project or the way it is being conducted, and would like to speak to someone independent of the project, please contact: Director, Research Ethics & Governance, The Royal Children's Hospital Melbourne on telephone: (03) 9345 5044.

The following document provides the plain language description of the project that was provided to patients in Study 1. Similar information letter was provided to the patient's carers to seek their permission for their kids to participate in the study. Parent's consent was compulsory as the study was conducted with kids under 18 years of age.

THE UNIVERSITY OF MELBOURNE

The Royal Children's Hospital Melbourne

INFORMATION LETTER

HREC Project Number: 35112A

Project Title: Understanding the user experiences of teleconsultation sessions

Investigators: Deepti Aggarwal, Dr. Bernd Ploderer, A/Prof. Frank Vetere and Susan Jury

Dear Participant,

What is the research project about?
The purpose of this study is to investigate the user experience of using teleconsultation systems. By teleconsultation, we mean a video consultation between a patient and doctor for diagnostic or medical advice. The aim of this study is to understand how teleconsultations happen, what technology is used, and what technology challenges are faced. This study will be valuable for designing future technology for teleconsultation sessions.

This project will form a part of Deepti Aggarwal's PhD research, and has been approved by the Human Research Ethics Committee (HREC) at the Royal Children's Hospital.

Who is funding this research project?
Funding for this project will come through the student researcher's PhD scholarship from the University of Melbourne.

Why am I being asked to be in this research project?
We are looking for people who are involved in a teleconsultation or face-to-face consultation as a patient, doctor, or carer. We would like to invite you to participate in the study because your child is seeking medical support from RCH. The information you provide will help us in gaining insights on the abilities and limitations of the current teleconsultation systems.

What does participation in this research involve?
This study has two parts: **observation** of a consultation session (teleconsultation or face-to-face consultation) and an **interview**. You can choose to participate in either one or both parts of the study.

If you choose to participate in the **observation**, a researcher (from non-medical background) will sit with you in your consultation session. We will take notes on the communication and interactions that happen during a medical consultation between patients and doctors. In this regard, we will not include specific medical information in our notes. Notes about medical information will only be taken in general terms to convey how such information is communicated, for instance, through technology (e.g., laptop) or other artefacts (e.g., paper based forms). We may also take photographs of the setup (without any people) before or after the consultation to record the arrangement and setup of technology in this context. Observations will happen at the doctor's place. It does not require any activity from your side.

We would also like to conduct **an interview** with you and your parent/guardian (together) afterwards to reflect upon your overall perception about the role of technology in supporting medical consultation. The sample questions include: What devices did you use to have a video consultation with your doctor?; What difficulties did you face while talking to your doctor through video? How would you differentiate video consultations from face-to-face consultations? This interview will be at a time and place convenient for you, or via telephone or video chat. The interview will last for approximately 20-30 minutes. We would like to make an audio recording of our conversations. This helps us to study the discussion in detail.

What are my alternatives to taking part?
Your participation in this study is completely voluntary. If you do not take part, or choose to withdraw from the project, it will not affect your access to the best available treatment options, care and educational support from The Royal Children's Hospital.

You are free to withdraw from the project at any time without telling us why. If you withdraw, we would like to use any information that we have already collected after seeking your permission.

What are the potential benefits for me and other people in the future?
You will have an opportunity to reflect on your experiences with the teleconsultation systems, which may help you to vent possible frustration with current systems and to develop greater skills. Some participants may appreciate an opportunity to have a voice in improving the services and technologies that they are using. Furthermore, you will assist us in designing future teleconsultation systems.

What are the possible risks, side effects, discomforts, and/or inconveniences?
We don't expect that this study introduce any risks. However, we do understand that having a researcher sitting in the consultation or discussing the concerned medical information could make you feel uncomfortable. Please feel free to ask the researcher to leave the room at any time to discuss your private information with the doctor. Likewise, we have done our best to make sure that the interview questions do not cause you any distress. However, you are free not to answer the question if you feel uncomfortable.

If we ask questions regarding your interaction with the technology, our aim is to evaluate the strengths and weaknesses of the technology and not to judge your technical knowledge. If the researcher observes or discusses the session's medical information, we want to assure you that we will not record specifics of this information. Medical information will only be recorded in general terms to convey how such information is communicated through technology in line with the research aim of understanding how technology is used to communicate over a distance.

Also, researchers are not associated with Royal Children's Hospital and have no influence on the provision of the health service. Additionally, researchers are also not from medical background, therefore, if you need medical support, we advise you to speak to your doctor or nurse.

What will be done to make sure my information is confidential?
In this study we will collect and use personal and health information about your child for research purposes. In this regard, information about private medical data will not become a part of this research. Additionally, any information we collect that can identify your child will be treated as confidential and used only in this project unless otherwise specified. We can disclose the information only with your permission, except as required by law.

All the information collected will be stored securely in the Department of Computing and Information Systems at the University of Melbourne for 7 years after the youngest participant turns 18 years of age. After this time, we will destroy it. All the electronic files will be password protected and kept on computers in the secured offices to which only members of the research team and the RCH ethics committee will have access.

The stored information will be re-identifiable. This means that we will remove identifying information such as your child's name and give the information a special code number. Only the research team can match your child's name to the respective code number, if it is necessary to do so. Personal information apart from the age and gender will not be revealed. At the end of the study, results may be presented at conferences or published in medical journals. In all such cases, we will use a pseudonym if we need to refer you.

Will I be informed of the results when the research project is finished?
At the end of the project, we will send you a summary of the project's results, if you provide your mail address in the consent form. Please be mindful that the findings will be an indicative of the whole group of the participants and not of every individual.

The full report of this study results will be disseminated through peer-reviewed publications and conference presentations across the research communities in health, and technology.

From where can I get further Information?
Should you require any further information, or have any concerns, please do not hesitate to contact any of the following people:

- Deepti Aggarwal (daggarwal@student.unimelb.edu.au, 0 47007 3052)
- Dr. Bernd Ploderer (ploderer@unimelb.edu.au, 03 8344 1511)
- Assoc. Prof. Frank Vetere (f.vetere@unimelb.edu.au, 03 8344 1496)

- Susan Jury (susan.jury@rch.org.au , 03 9345 4645)

How do I agree to participate?
If you would like to participate, please read and sign the attached Consent Form. Please return the signed form either as a scanned copy or a photograph to the student researcher (Deepti Aggarwal). You can also hand it over to your doctor during your next visit to the hospital. You may keep a copy of the Information Letter and Consent Form for your reference.

Thank you for your help.

Yours sincerely,

Deepti Aggarwal
PhD Candidate
Dept. of Computing and Information Systems
The University of Melbourne

Bernd Ploderer
Lecturer
Dept. of Computing and Information Systems
The University of Melbourne

Frank Vetere
Associate Professor
Dept. of Computing and Information Systems
The University of Melbourne

Susan Jury
Manager
Telehealth Services
Royal Children's Hospital, Melbourne

If you have any concerns about the project or the way it is being conducted, and would like to speak to someone independent of the project, please contact: Director, Research Ethics & Governance, The Royal Children's Hospital Melbourne on telephone: (03) 9345 5044.

A.2. Tool to Record Pain at the Hospital

At the collaborating hospital, patients fill in a pain scale diagram to describe their pain characteristics like pain location, intensity and activities that trigger pain. Clinicians refer to these pain diagrams in the following consultations to compare and understand the patient's recovery. Patients fill in a fresh pain diagrams after a couple of consultations to record their pain characteristics during the course of treatment at the hospital. The following pain diagram was filled in by a patient in her initial consultation with her physiotherapist. This diagram was referred to in Section 4.4.2 in the thesis.

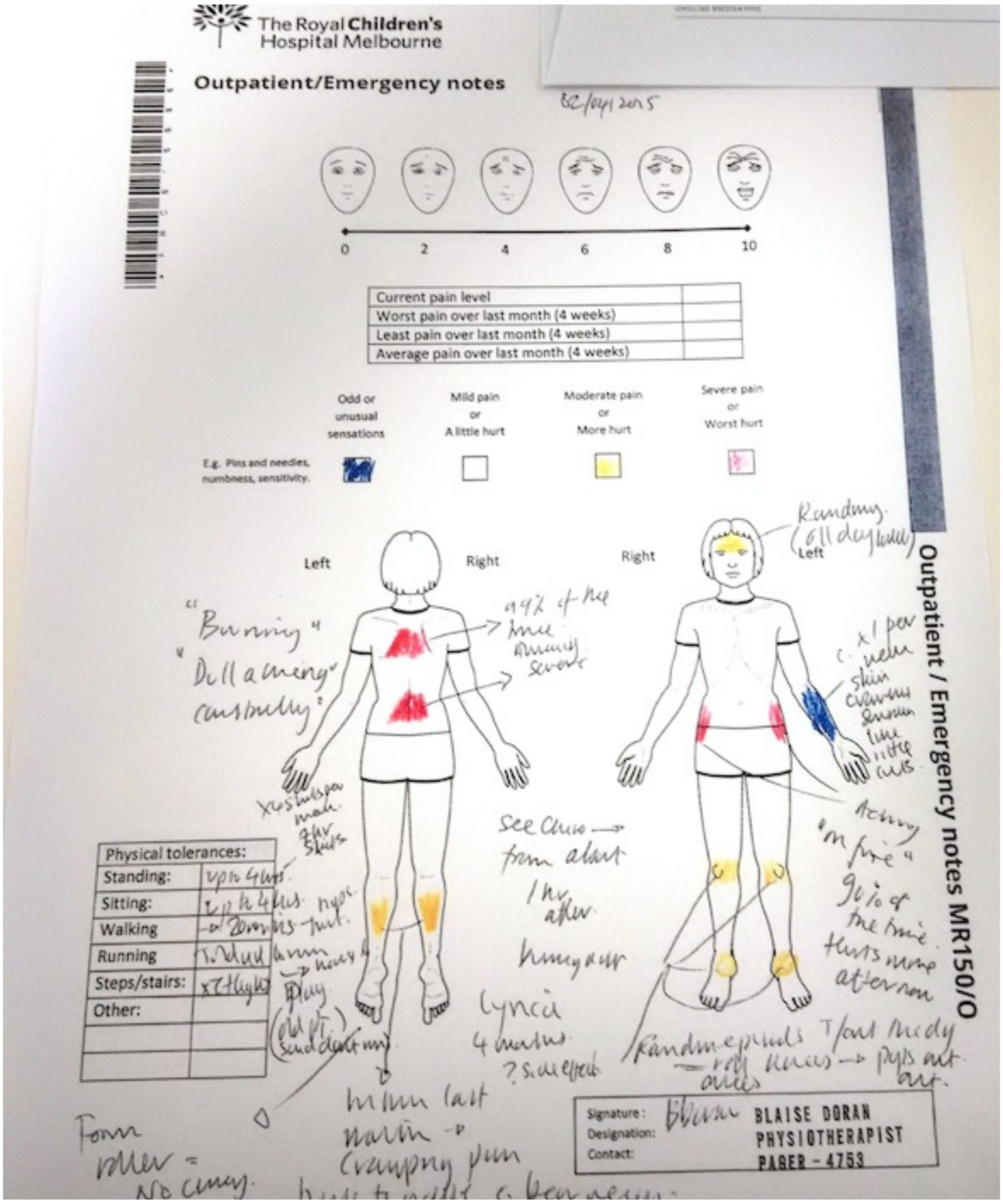


Figure: Pain Scale Diagram used by the patients to record their pain intensity.

A.3. Daily Logs Maintained by the Patients

Patients at the collaborating hospital were advised to maintain a manual log of their everyday physical activities using paper based diaries. Patients used different colors and patterns to plot their activities. The following image is the log maintained by a patient, where she used different colors to denote different activities performed on different days. Some patients use separate plots to log in different activities. The x-y axis in the plot represents the duration (in minutes) of the activity performed on different days. Patients bring these logs in face-to-face consultations to discuss their activity schedule with their physiotherapist. This document was referred to in Section 4.4.2 in this thesis.

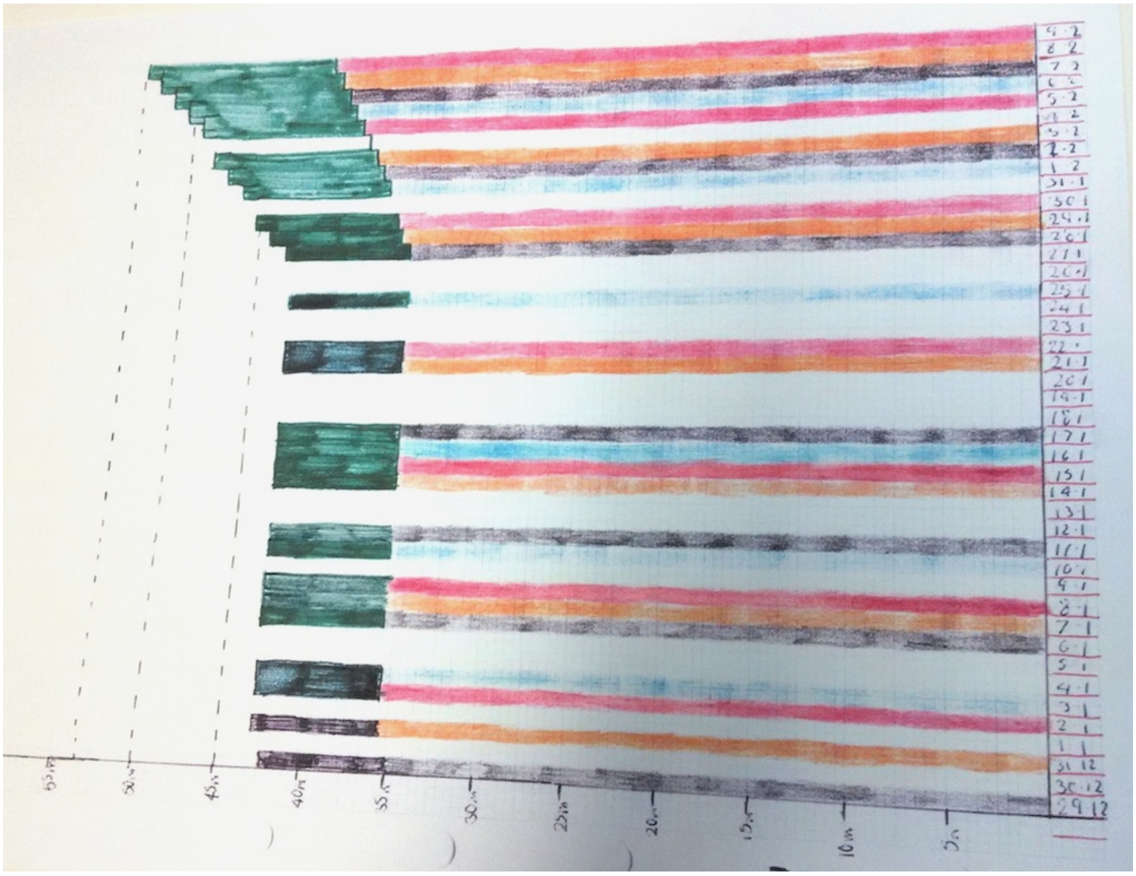


Figure: Patients manually logged their daily routine on paper based charts.

A.4. Observation Guide

The following document lists the observation guide that I used to capture field notes while being present in the face-to-face and video consultations. The guide was a part of the ethics application approved by the Ethics Advisory Group at the Royal Children's Hospital. Below I present the guide developed in the beginning of the study. I refined this guide throughout the study as my understanding of the research problem and the context developed over time. This document was referred to in Section 4.4.3 in this thesis.

I conducted observations of both face-to-face and teleconsultation sessions in order to understand the following:

- Understand the setup of teleconsultation session
- Understand the process of teleconsultation session
- Understand the interactions (both verbal and non-verbal) during the session
- Understand the difference between teleconsultations and face-to-face consultations
- Understand the limitations of the current teleconsultation systems

Following are a set of questions related to each topic that guided the data collection.

Understanding the setup

1. Where is the session organized and why?
2. What is the setup of room?
3. How does the room setup change before and after the consultation?
4. What technology is used for the session and for what purpose?
5. Who are involved in the session and what are their roles?
6. How do people arrange themselves around the available technology?
7. How do participants arrange themselves with respect to each other?

Understanding the process

1. What is the purpose of consultation?
2. Are both ends familiar to each other? (Introductory or follow-up consultation)
3. What is the sequence of teleconsultation? (Opening, complaint, examination, diagnosis, treatment and closing) What is the temporal relationship between two phases?
4. How does the teleconsultation progress?
5. How is the session supplemented with information related to the given health issue?
6. When do participants use cues/gestures?
7. What medical information is communicated verbally?

Understanding the interactions

1. What activities are performed by the individuals during the session?

2. Who interacts with whom and why?
3. How do participants interact with the technology and for what purpose?
4. What type of information gets exchanged (symptoms, test results and scans, physical
5. information like mobility and strength of limbs, pain, body language, emotional support, etc.)?

Understanding the difference between teleconsultations and face-to-face consultations

1. How is the conversation in teleconsultation different than the face-to-face consultation?
2. What are the differences in both consultations in terms of interaction with other people and artefacts?
3. What are the unique qualities of both consultations?

Understanding the limitations of current teleconsultation systems

1. What technical issues are faced during the consultation?
2. When did the technology break?
3. What do participants do during technical breakdown (like waiting, anticipating, interpreting the reason or consequences)?
4. What sorts of interactions/activities are limited by the current setup?

A.5. Description of Taking Field Notes

I utilised field notes to collect data from the field. These field notes involved two phases: first, taking quick notes in the consultation room and secondly, elaborating the quick notes to write a detailed account of the events unfolded in the session. I first describe the note taking process in the consultation room. This document was referred to in Section 4.4.3 in this thesis.

Taking Field Notes in Consultation Rooms

During a consultation, I took shorthand field notes to quickly capture the events unfolding in the session. These shorthand notes included texts and sketches. All the notes were manually taken in a notebook, as I was more fluent in writing and sketching with pen than taking digital notes. Initially, I also tried to develop a set of shorthand notations to help in the data collection. However, referring or memorising the defined set of notations in real-time delayed my note making process. And hence, I went with spontaneous note making process.

Since the focus of this thesis is on bodily communication, I made significant use of sketches to take notes related to the bodily information such as orientation of different participants, which was otherwise difficult to capture in text. Not only the sketches made data collection easier, they also made participants relaxed with the data collection. Participants could easily have a quick glance on the sketches to check what I was capturing. These sketches helped me in building trust with the clinicians as they felt ensured that I was not taking specific notes related to the patient's condition or any other private data from the patient's record.

Below I illustrate how I took field notes in the session by using snapshots of the face-to-face consultation (session 7) of Laura with her physiotherapist, Phil from my field notes diary. The session was accompanied by other clinicians - a pain consultant and two trainees, and Laura's mother. Please note that I changed the actual names of the participants written in the field notes with pseudonyms used in Chapter 4.

I began the notes from a snapshot of the room with details of the underlying technology, arrangement of the participants with respect to the technology and each other, and their physical appearance. The image below shows notes on the participants arrangement with information on their body language and spatial orientation in the room. Details of the body language although was more important to record the patient's condition but also provided pointers to other participants' overall attitude in the session. This helped me to preserve the visual memory of the session so as to refresh the events afterwards.

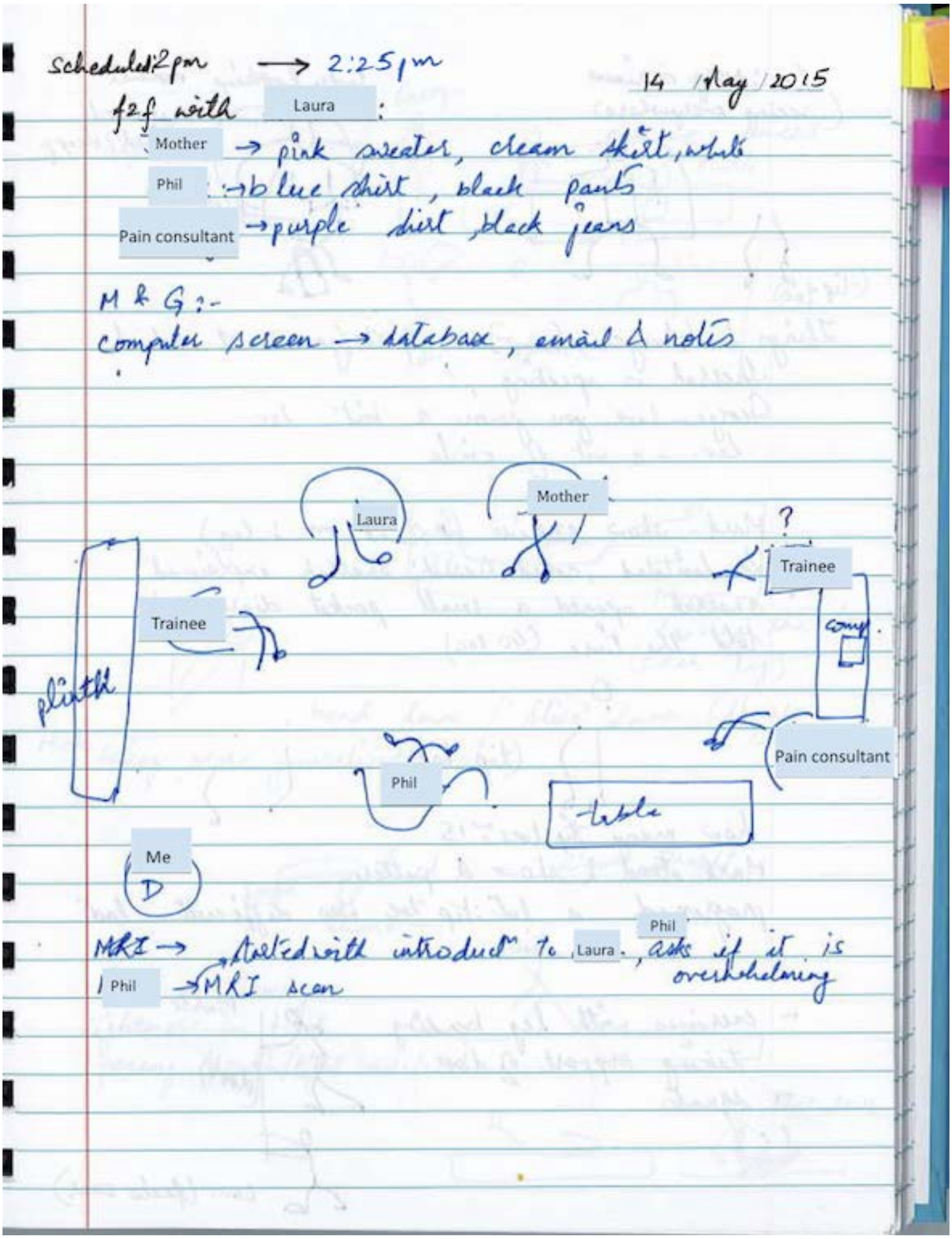


Figure: Field notes capturing the arrangement of the participants in the face-to-face session of Laura with Phil.

The field notes were supported by the photographs so as to capture the consultation visually. I captured multiple photographs of the room (in the absence of patients) to record the room arrangement and the underlying technology, as shown below.

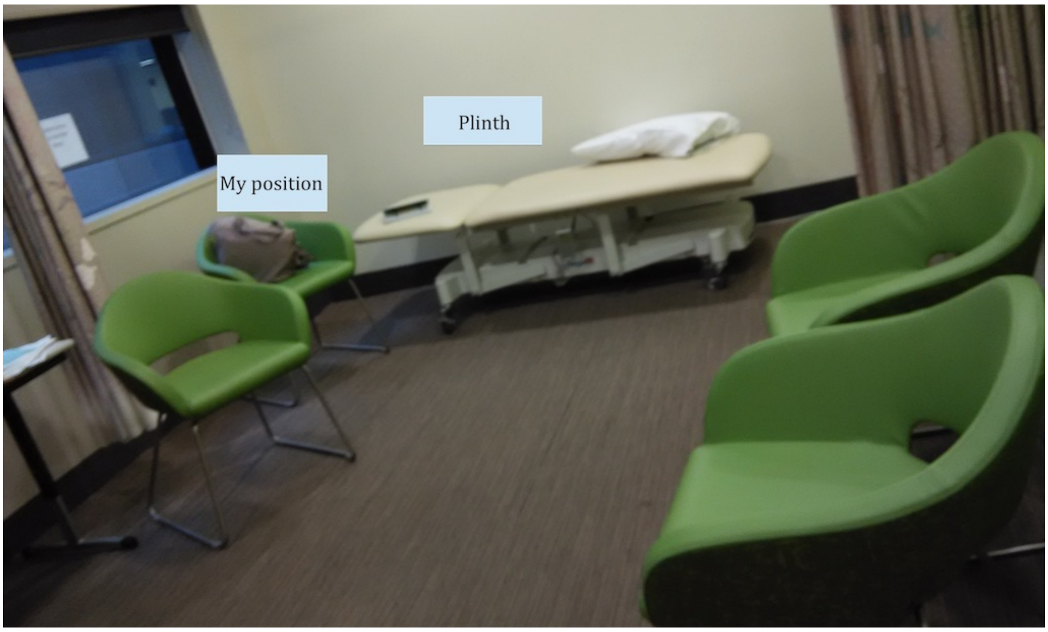


Figure: Arrangement of the room where face-to-face consultation of Laura was organised.

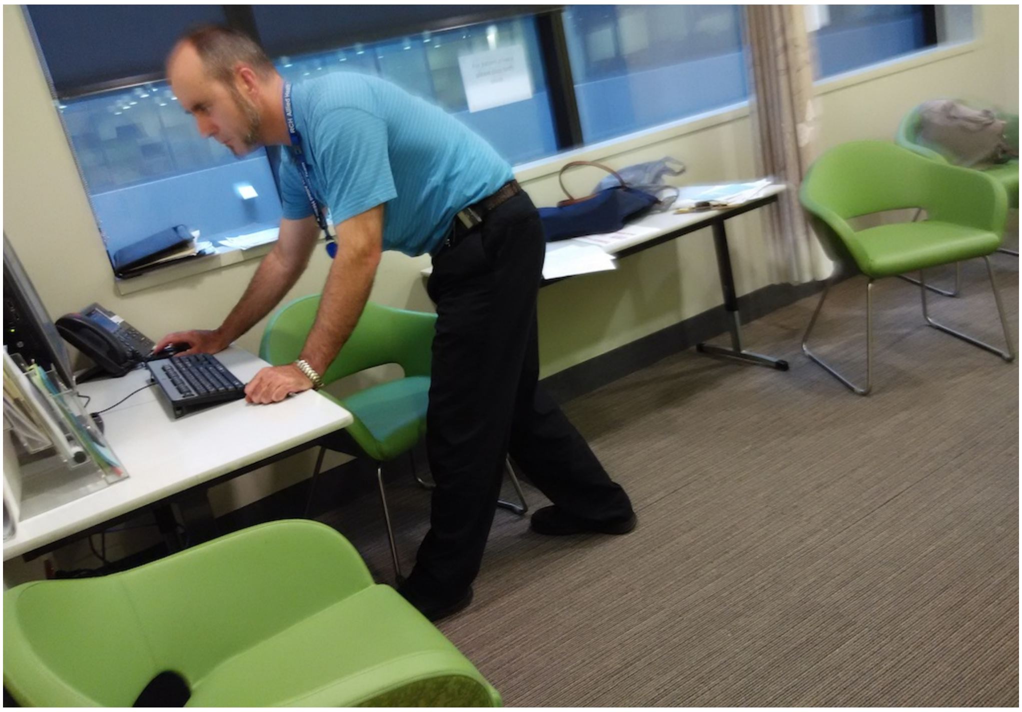


Figure: Another side of the room had a computer system that clinicians used to refer to the patient's medical history.

As the session unfolded, I drew quick sketches to record the exercises that the patient and physiotherapist performed, and took notes on the conversation between the participants. The following image illustrates the sitting arrangement of Laura as she continued sitting on tip-toe position, with her front foot touching the ground. It also illustrates two exercises - tip toes and wall push ups, that Phil and Laura performed.

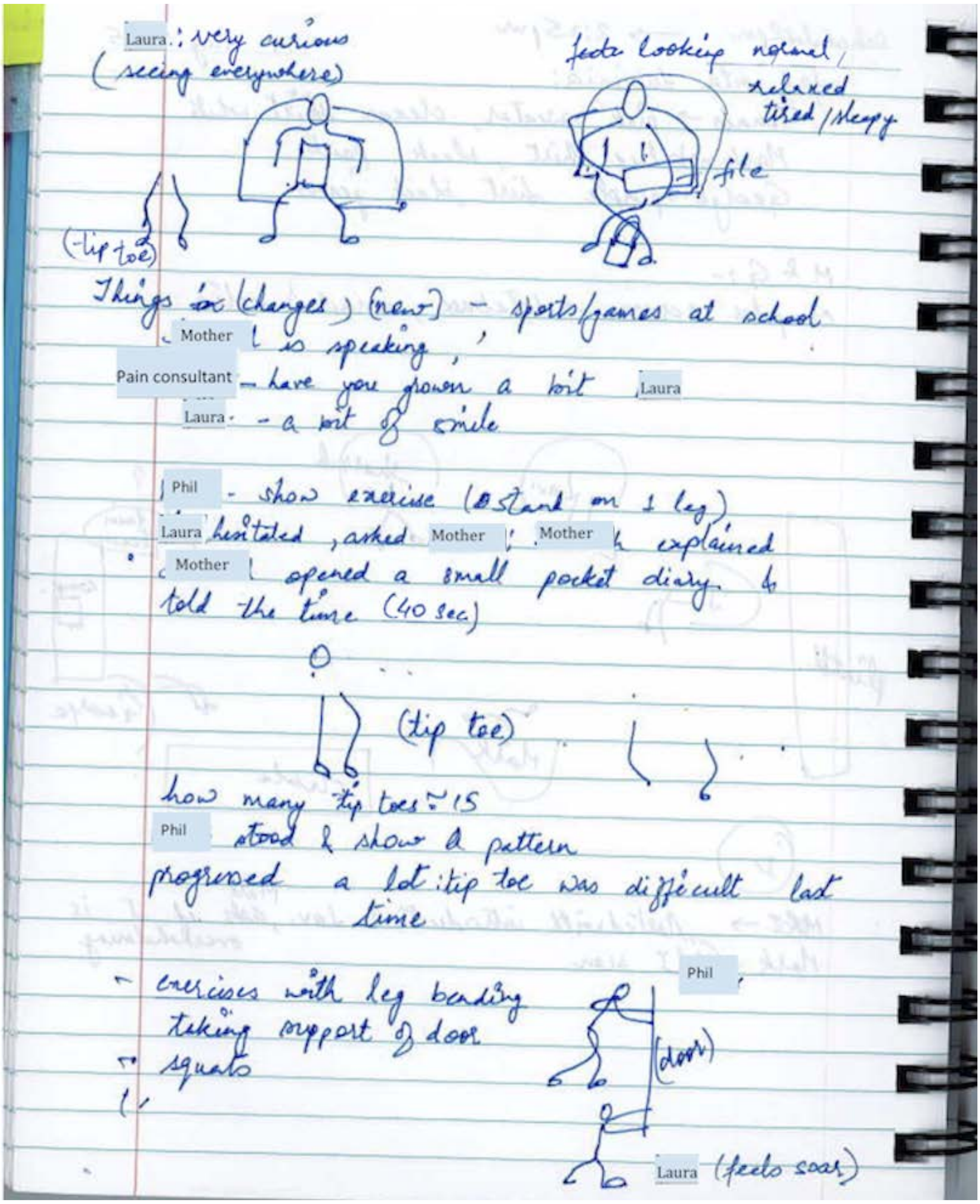


Figure: Field notes capturing the exercises performed by Laura and Phil and the conversations between participants.

Following these exercises, Phil conducted physical assessment of Laura to understand her recovery. The following image shows the activities performed by Phil and Laura. Laura lied down on the plinth, and Phil examined her knees and legs for body tightness and pain.

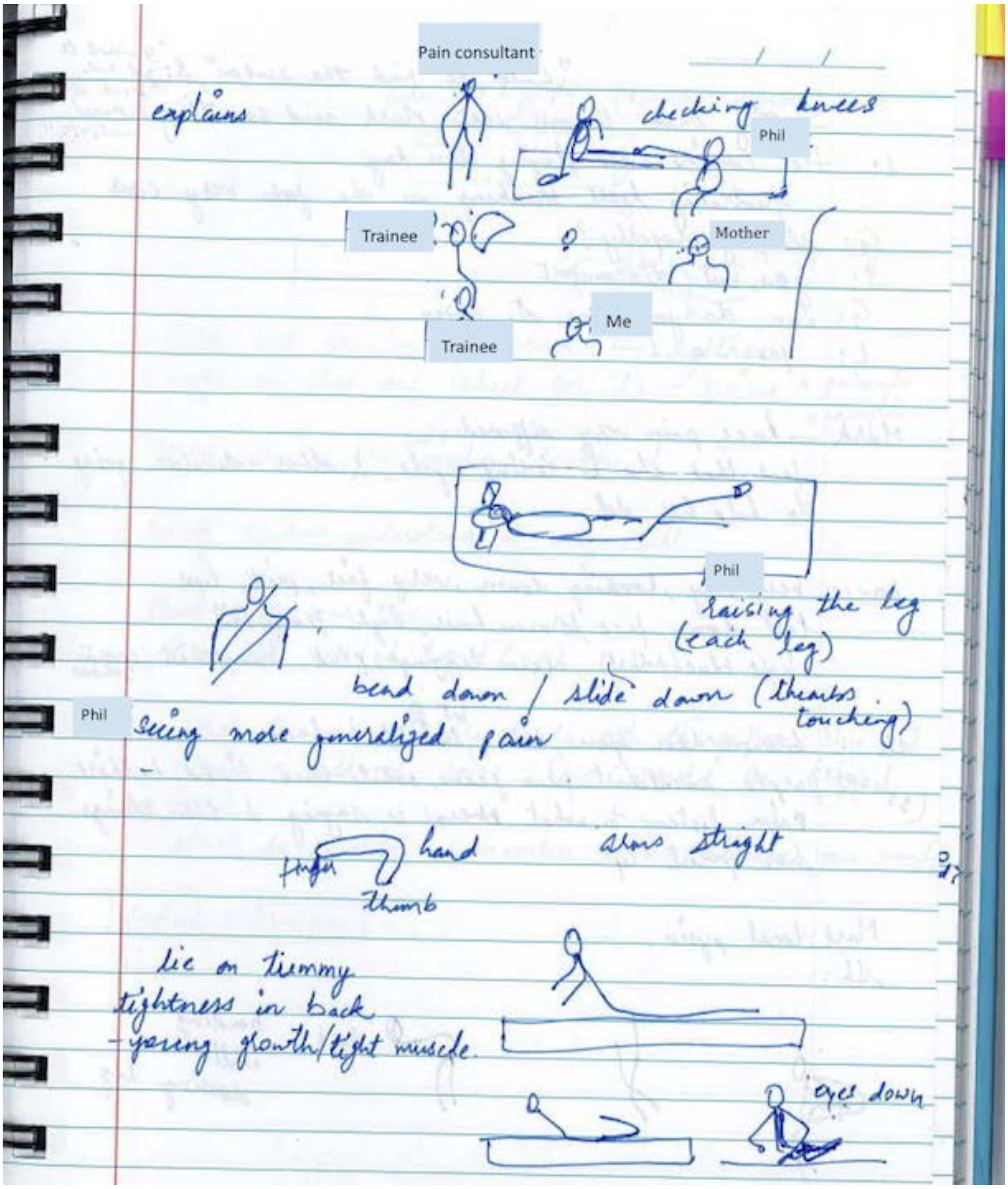


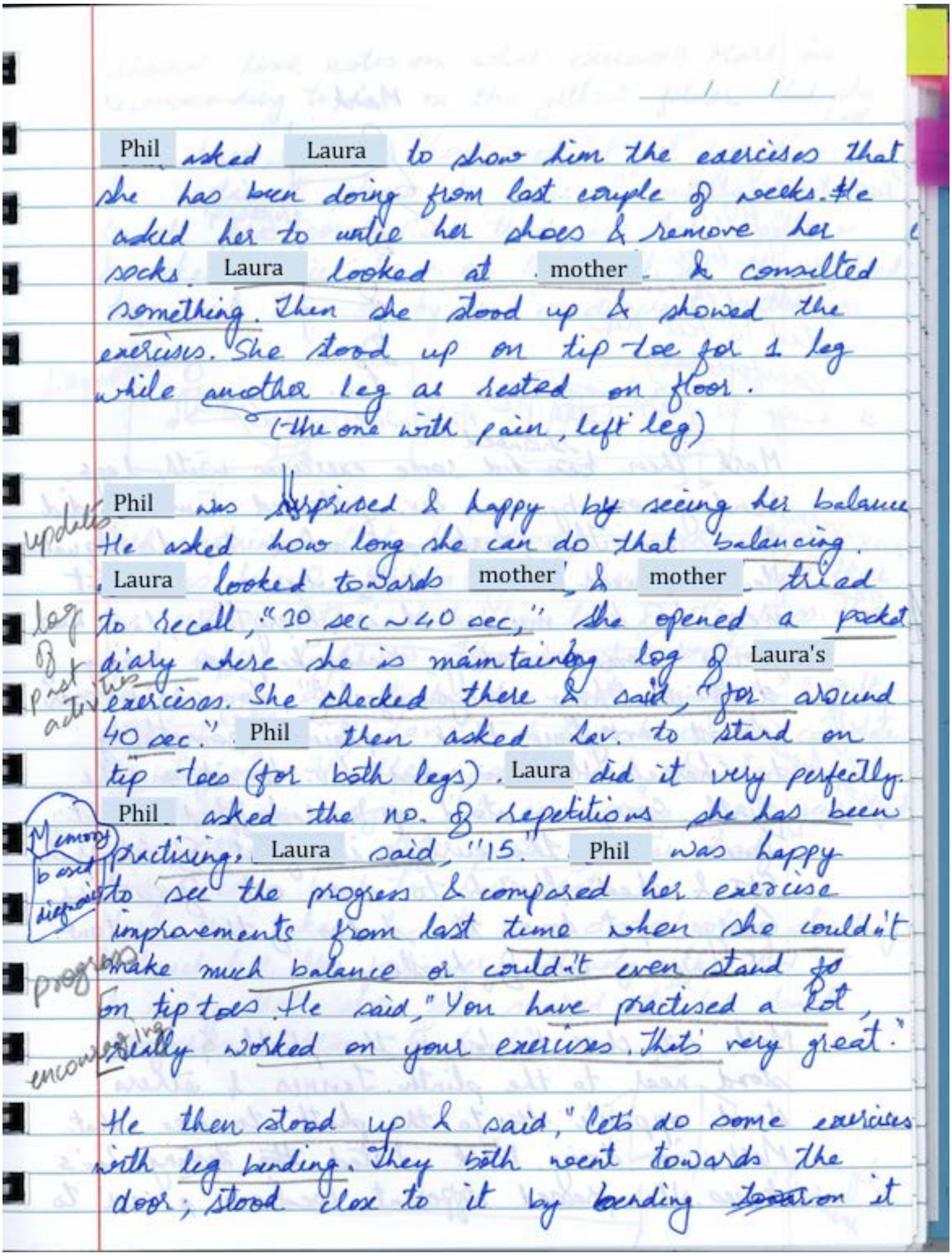
Figure: Field notes capturing the physical assessment of Laura as performed by Phil.

Developing Elaborated Field-Notes

Post consultation, these shorthand notes provided me a recap of the session and refreshed my visual memory. I used these pointers to write detailed account of the events that unfolded in the consultation. Again, these notes included texts and sketches. Also, all the notes were manually taken in a notebook, as I was more fluent in writing and sketching with pen than taking digital notes. I used different colored pens to write these notes, to highlight different events of the session. As I was writing, I started coding the data by highlighting the key incidents through a pencil.

Below I provide snapshots of the elaborated field notes for the same session explained above with Laura (session 7), with codes written in pencil. These codes were iteratively refined as I conducted observations of new sessions - I continued adding more codes in the notes of the previous sessions.

The following image shows that Laura's mother provided updates on her recovery and her exercise routine. Laura's mother was maintaining a diary to keep record on her recovery.


Phil asked Laura to show him the exercises that she has been doing from last couple of weeks. He asked her to untie her shoes & remove her socks. Laura looked at mother & consulted something. Then she stood up & showed the exercises. She stood up on tip-toe for 1 leg while another leg was rested on floor. (the one with pain, left leg)

updates
Phil was surprised & happy by seeing her balance. He asked how long she can do that balancing. Laura looked towards mother & mother tried to recall, "30 sec ~ 40 sec," she opened a pocket diary where she is maintaining log of Laura's exercises. She checked there & said, "for around 40 sec." Phil then asked Lau. to stand on tip toes (for both legs). Laura did it very perfectly. Phil asked the no. of repetitions she has been practising. Laura said, "15". Phil was happy to see the progress & compared her exercise improvements from last time when she couldn't make much balance or couldn't even stand on tip toes. He said, "You have practised a lot, really worked on your exercises. That's very great."

log of past activities
Memory based responses
progress
encouraging

He then stood up & said, "let's do some exercises with leg bending. They both went towards the door, stood close to it by bending ~~towards~~ on it

Figure: Details of the conversations between participants.

The following snapshot provides details on how Phil and Laura performed exercises during the face-to-face session. Since, Laura was introvert, Phil performed exercises with her to make her feel comfortable.

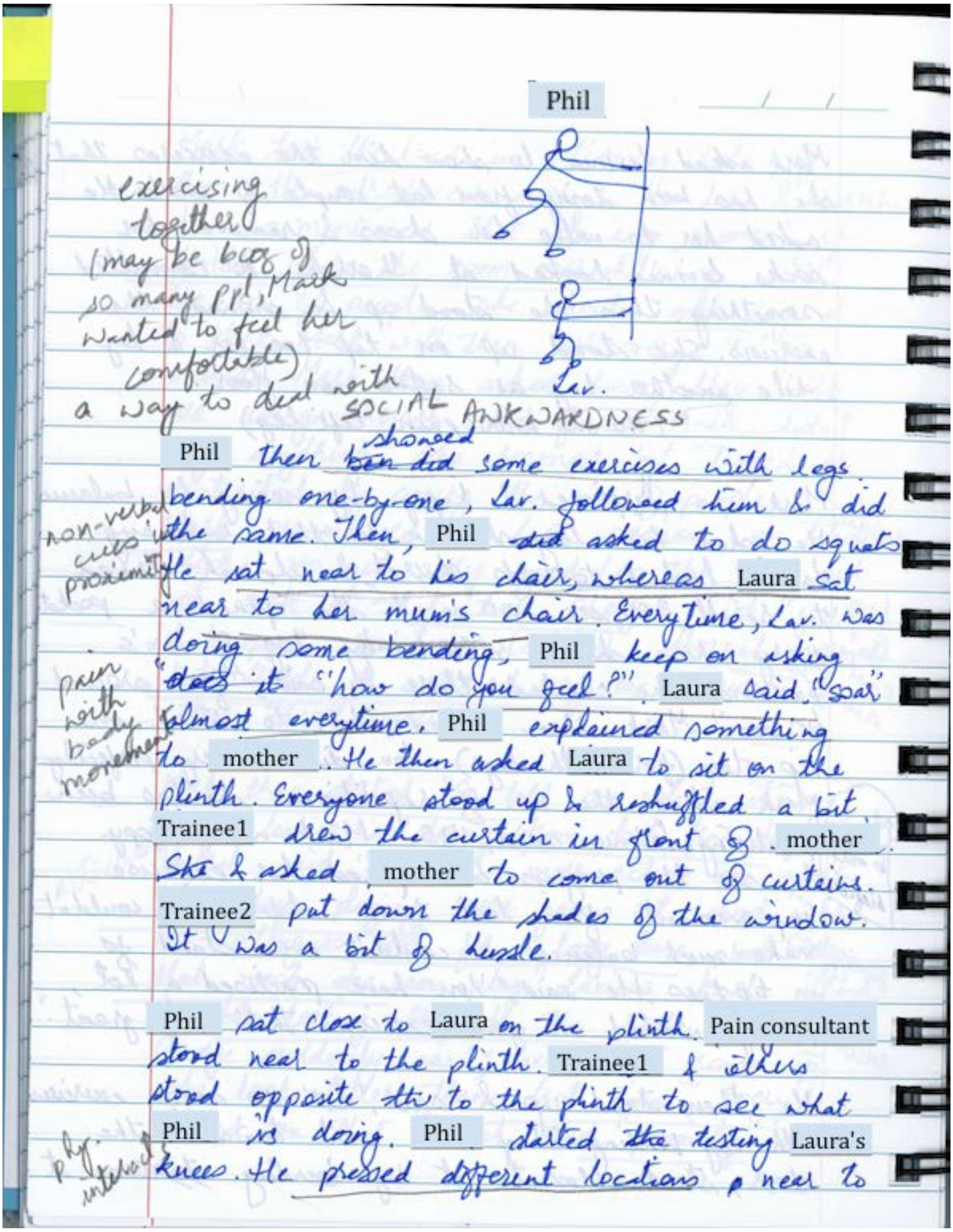
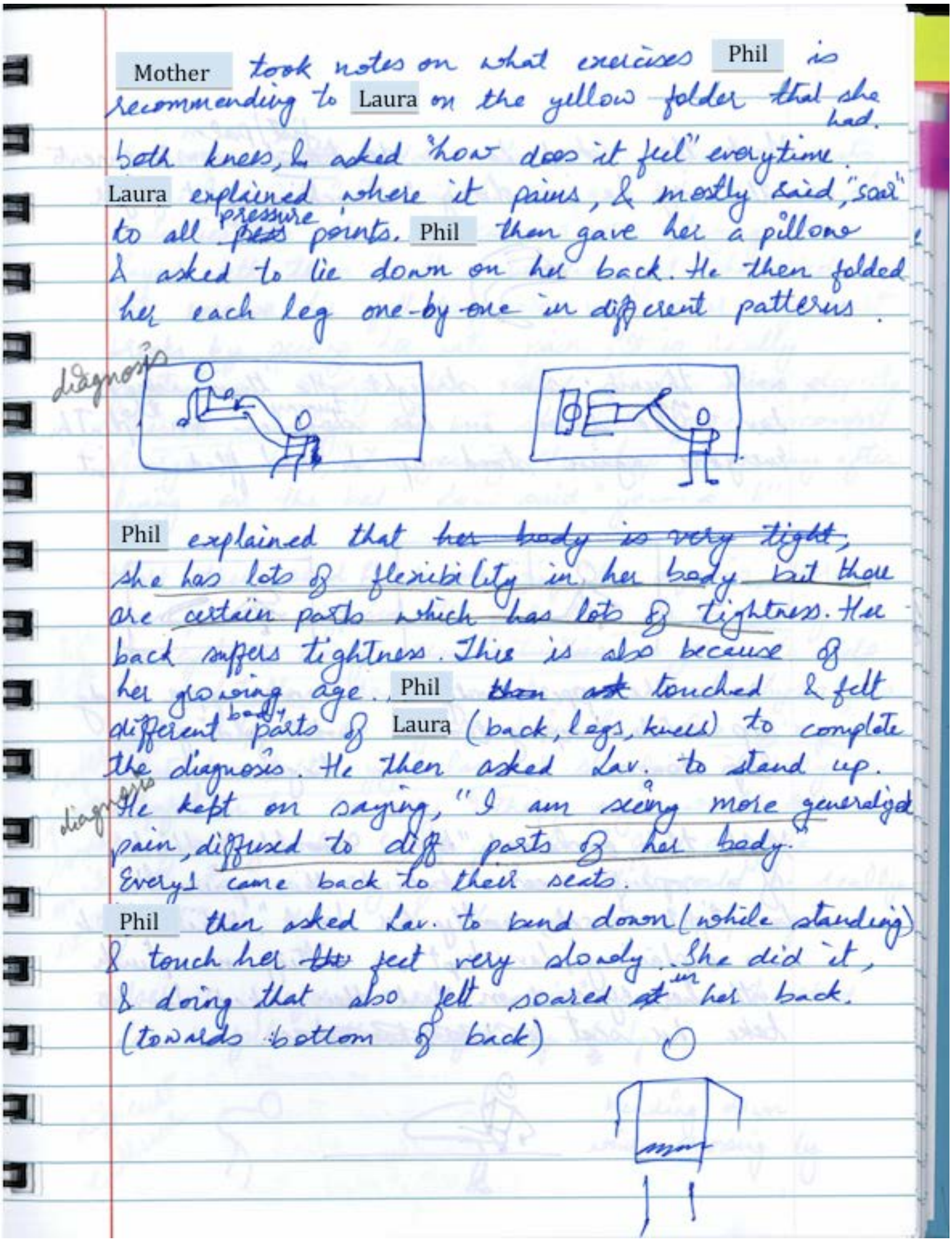


Figure: Details of the exercises performed by Laura and Phil.

The following description illustrates how Phil performed physical assessment of Laura on a plinth. He checked for the body tightness and pain locations in different body parts.


Mother took notes on what exercises Phil is recommending to Laura on the yellow folder that she had.
both knees, & asked "how does it feel" everytime.
Laura explained where it pains, & mostly said "sore" to all ~~pres~~ pressure points. Phil then gave her a pillow & asked to lie down on her back. He then folded her each leg one-by-one in different patterns.

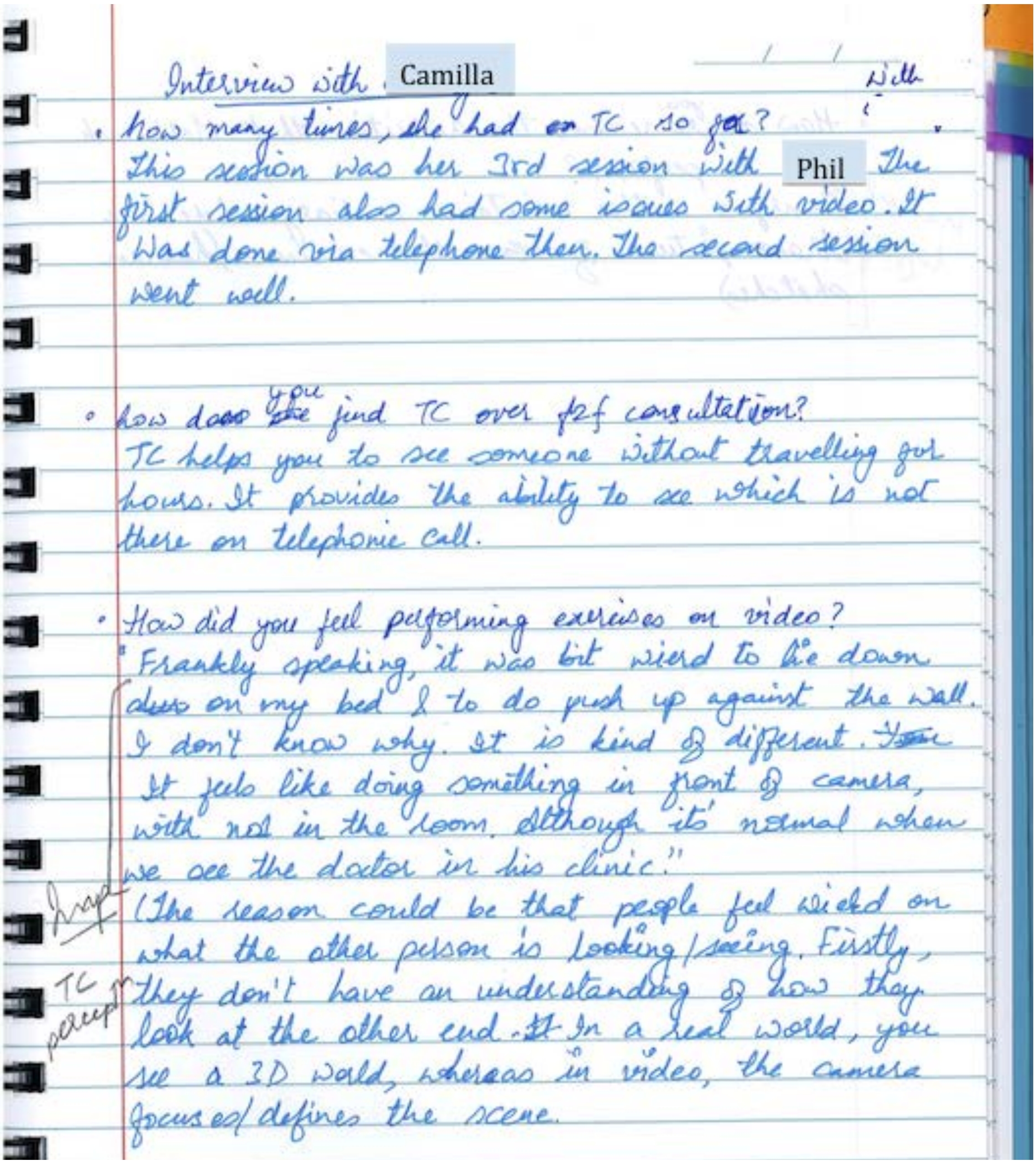
diagnosis

Phil explained that ~~her body is very tight,~~ she has lots of flexibility in her body but there are certain parts which has lots of tightness. Her back suffers tightness. This is also because of her growing age. Phil ~~then ask~~ touched & felt different body parts of Laura (back, legs, knees) to complete the diagnosis. He then asked Lau. to stand up.
diagnosis He kept on saying, "I am seeing more generalized pain, diffused to diff. parts of her body."
Every1 came back to their seats.
Phil then asked Lau. to bend down (while standing) & touch her ~~the~~ feet very slowly. She did it, & doing that also felt soared ~~at~~ in her back. (towards bottom of back)

Figure: Elaborated field notes describing the physical assessment of Laura.

A.6. Snippet of the Informal Conversation

Below I provide a snapshot of the transcribed conversation with Camilla from my field notes diary. This conversation happened in a video consultation (session 8) when Camilla was waiting for another clinician after finishing the conversation with Phil. Camilla described that she felt awkward in doing the exercises by lying down on the bed during the session. (This document is referred to in Section 4.4.3.)



Interview with Camilla / / Will

• how many times, she had on TC so far?
This session was her 3rd session with Phil. The first session also had some issues with video. It was done via telephone then. The second session went well.

• how does you find TC over f2f consultation?
TC helps you to see someone without travelling for hours. It provides the ability to see which is not there on telephonic call.

• How did you feel performing exercises on video?
"Frankly speaking, it was bit wierd to lie down also on my bed & to do push up against the wall. I don't know why. It is kind of different. It feels like doing something in front of camera, with not in the room. Although it's normal when we see the doctor in his clinic."
Imp
(The reason could be that people feel wicked on what the other person is looking/seeing. Firstly, they don't have an understanding of how they look at the other end. In a real world, you see a 3D world, whereas in video, the camera focuses/defines the scene.
TC percep

Figure: Excerpt of the informal conversation with Camilla from session 8.

A.7. Interview Guide

The following document lists the interview questions that guided my interviews with the participants. This guide was a part of the ethics application approved by the Ethics Advisory Group at the Royal Children's Hospital. Here, I present the revised guide that I prepared in the beginning of the study. I refined this guide throughout the study as my understanding of the research problem and the context developed over time. This document was referred to in Section 4.4.3.

The purpose of interviewing participants was to:

- Understand the participant's background: prior experience with teleconsultation sessions, and familiarity with the technology
- Understand the setup of teleconsultation session
- Understand the user experience
- Understand how participants find teleconsultations different from face-to-face consultations
- Understand the limitations of the current technology

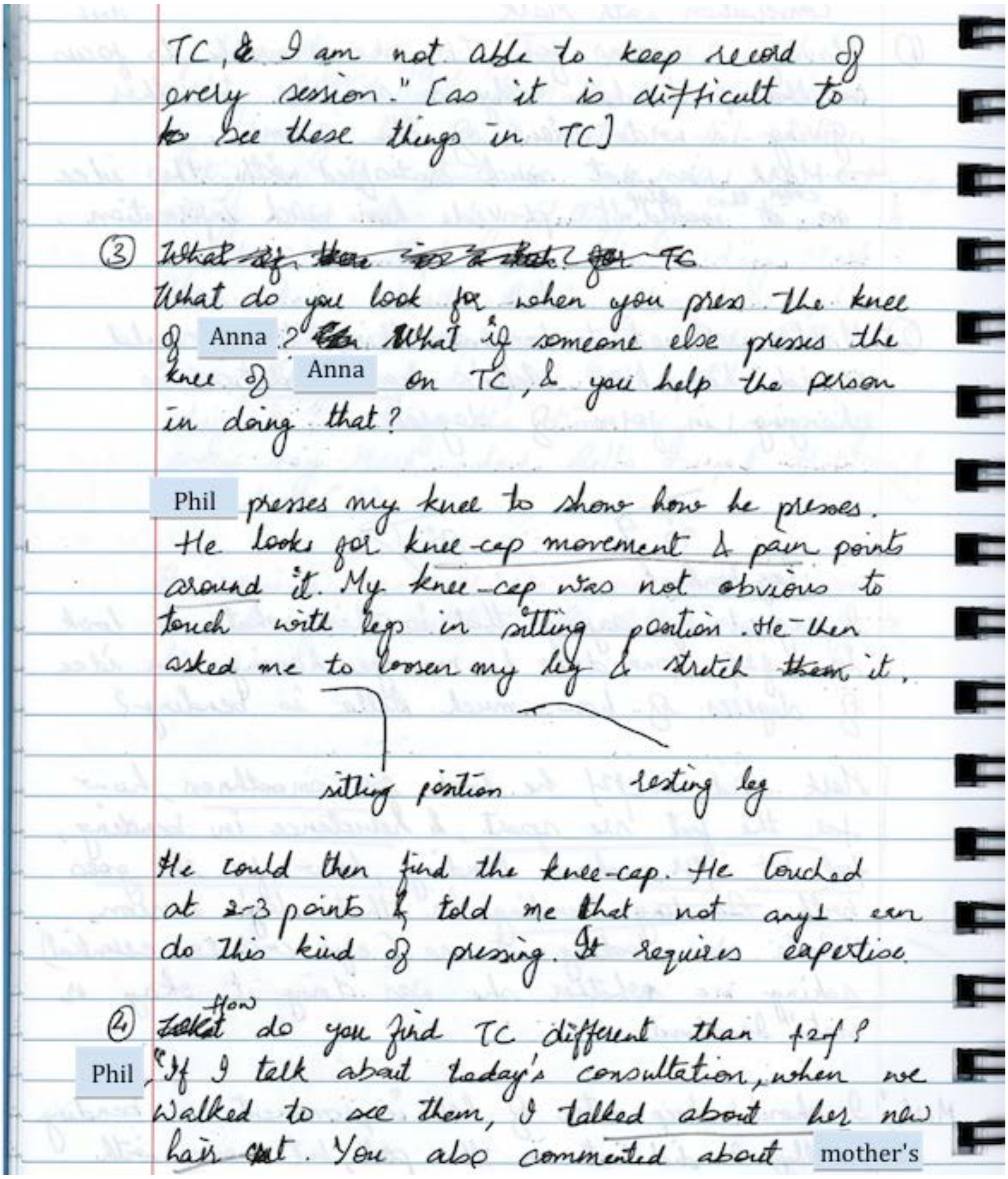
Following are a set of sample interview questions that I used these questions flexibly in the interviews depending on the course of the conversation.

Participants	Questions
Child and Carer *(carer will assist the child to answer questions)*	○ How familiar are you with video calls such as Skype? ○ How do you find talking to your doctor through video? ○ What do you think about video consultations in terms of lack of physical touch of your doctor? ○ What difficulties do you face when talking to your doctor through video? ○ What technology or device did you use to have a video consultation? ○ How did you share your child's medical report with the doctor? ○ How would you differentiate video consultations from face-to-face consultations? ○ How would you have continued today's consultation in the face-to-face setting? ○ What technical issues did you face while arranging today's session?
Clinician	○ How many video consultations have you had earlier? ○ Can you describe me the setup of today's consultation?

	○ What technology did you use to facilitate the session? ○ How is this setup different from the setups of your earlier sessions? ○ What do you think about video consultations in terms of supporting a clinician-patient consultation? ○ What do you think about video consultations in terms of lack of physical touch? ○ What is it that you want to communicate but cannot in a video consultation? ○ How would you have continued today's consultation in the face-to-face setting? ○ When do you prefer to have video consultation with your patient? ○ What is an ideal teleconsultation for you?

A.8. Summarising Interviews into Notes

Below I provide snapshots of the short summary developed immediately after each interview. This excerpt belonged to the discussion with Phil after session 3 with Anna, where he described that physical examination of knee-cap is easier to conduct in face-to-face consultations than video consultations. This document is referred to in Section 4.4.3 in the thesis.



TC, & I am not able to keep record of every session." [as it is difficult to ~~to~~ see these things in TC]

③ ~~What if there is a that? for~~ TC
What do you look for when you press the knee of Anna? ~~the~~ What if someone else presses the knee of Anna on TC, & you help the person in doing that?

Phil presses my knee to show how he presses. He looks for knee-cap movement & pain points around it. My knee-cap was not obvious to touch with legs in sitting position. He then asked me to loosen my leg & stretch ~~them~~ it,

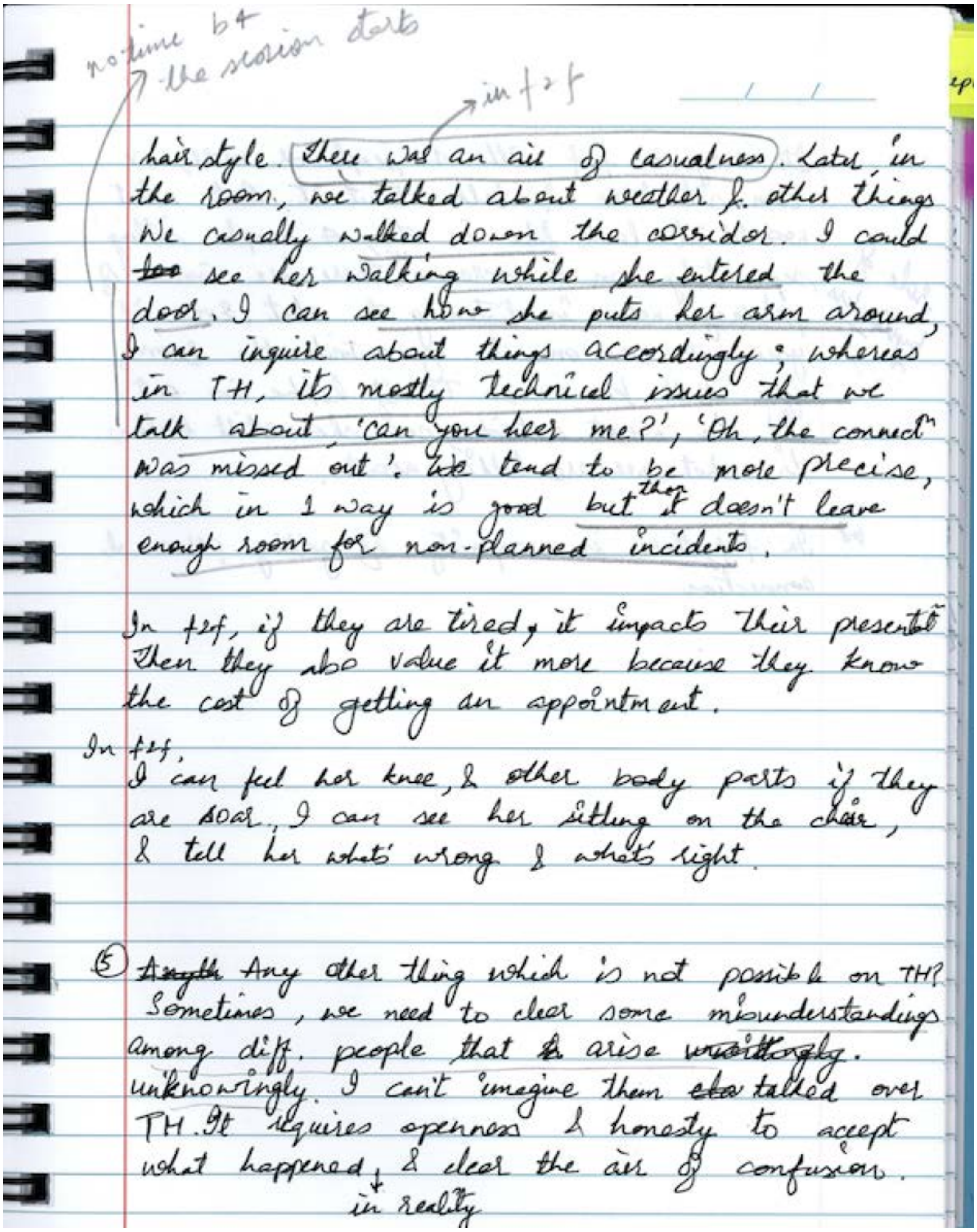
sitting position   resting leg

He could then find the knee-cap. He touched at 2-3 points & told me that not any1 can do this kind of pressing. It requires expertise.

④ ~~What~~ How do you find TC different than f2f?
Phil, "If I talk about today's consultation, when we walked to see them, I talked about her new hair cut. You also commented about mother's

Figure: Excerpt of the informal conversation with Phil from session 1.

He also described that face-to-face consultations allow more personal conversations with the patient than video consultations.



no time b4 the session starts

in f2f

hair style. There was an air of casualness. Later, in the room, we talked about weather & other things. We casually walked down the corridor. I could ~~too~~ see her walking while she entered the door. I can see how she puts her arm around, I can inquire about things accordingly; whereas in TH, its mostly technical issues that we talk about 'can you hear me?', 'Oh, the connectn was missed out'. We tend to be more precise, which in 1 way is good but then it doesn't leave enough room for non-planned incidents.

In f2f, if they are tired, it impacts their presentn. Then they also value it more because they know the cost of getting an appointment.

In f2f, I can feel her knee, & other body parts if they are sore. I can see her sitting on the chair, & tell her what's wrong & what's right.

⑤ ~~Anyth~~ Any other thing which is not possible on TH? Sometimes, we need to clear some misunderstandings among diff. people that ~~a~~ arise ~~unwittingly~~. unknowingly. I can't imagine them ~~else~~ talked over TH. It requires openness & honesty to accept what happened, & clear the air of confusion. in reality

Figure: Excerpt of the informal conversation with Phil from session 1.

A.9. Snippets of the Data Analysis

This document provides the data analysis process for Study 1. This document was referred to in Section 4.4.4 in the thesis.

I utilised iterative approach to analyse the data, wherein after every consultation, I prepared a summary of key events that occured in all the previous sessions. Initially, this list included all the events that I found interesting in the sessions. After a couple of sessions, I started to list these activities across different phases mentioned in the literature to develop a comprehensive understanding of the context: Opening, History Taking, Examination, Diagnosis, Treatment and Closing. Apart from these six phases, I also added an additional phase called Waiting phase, which happens before the opening phase, and I numbered it as a zero phase. This phase included the activities that patients and clinicians perform in the absence of each other. This phase seemed important to me in the beginning however, in the final phase of writing the findings, I combined this phase with the Opening phase.

After finishing the data collection with ten sessions, I developed a detailed list of the activities performed by the participants in both face-to-face and video consultations. For both consultations, I structured the activities around seven phases with each phase describing four things: what happens in the phase, activities involving bodily movements, other highlights of the session and how does the phase advanced to the next phase. Along with this analysis, I also developed a separate list of the bodily cues that was relevant in the face-to-face and video consultations. After developing the individual lists for face-to-face and video consultations, I compared these lists to find out the challenges of bodily communication in video consultations. This comparison was directly written as findings of Study 1.

Below I first illustrate the analysis of face-to-face consultations and then describe the analysis of the video consultations.

Analysis of Face-to-face Consultations

I structured the key events from the study sessions across seven phases of the consultation: Waiting, Opening, History Taking, Examination, Diagnosis, Treatment and Closing.

Phases	What happens?	Bodily movements & non-verbal cues	Other highlights	How does the phase change?
Waiting	-> Patient & caregiver sitting with other people in the waiting room. They can talk to others, if required. -> Physio comes to take the patient to the consultant room. (not always)	-> Physio is looking at patient's walking and talking style. -> Physio also notices the caregiver's emotional state (overwhelmed, tired, troubled)	-> physio also notices other things such as different hair style (Bella), & increase in height (Lavinia) -> parent's change in hair style (early morning flight)	-> They walk together and share some short talks on the way -> Informal introduction of other people joining the consultation.
Opening	-> Patient reaches the room, figures out where to sit (spatial arrangement) -> formal introduction of who is involved in the session -> building rapport with short talks:: how was your flight? [[physio also brings up the things he noticed so far, e.g., change in hair style]] -> everyone is involved in the discussion:: positive environment	-> Physio notices patient's hesitation in sitting (weight distribution), talking (silent or talking) and body posture (e.g, Bella cuddling to the front)	-> Spatial arrangement: a big circle accommodating everyone; & a triangle or V-shape between the family members of the patient [[V-shape if patient is with one parent (mostly mother); and triangle when both the parents are with the patient.]] -> More people are involved (3-6 people) -> Physio refers to his handwritten notes or computer files -- does not see the patient/caregiver every time	-> Physio or parent switches to the complaint phase. Physio, "So tell me, what new things Lavinia is doing from last few days?" Mother brings the complaint with the short talks - Bella had pain while having hair cut Or Bella's shoulder is getting sore bcoz of cuddling to the front.
Complaint/ Update	→ With a new patient, physio asks for the issue that the patient is having -- patient/caregiver describes their pain in different body parts → For follow up sessions, physio asks for the updates on different exercises that he asked the patient to do. Caregiver/patient mentions the daily routine with the exercises, frequency and time dedicated for each exercise -- and how it is helping the patient and what are the issues → other conversations such as influence of pain on school attendance; in playing favorite games/activities; on sleep etc. They also discuss the discussion with other doctors, yoga instructors, results of tests/	→ tears in eyes, or hesitations in explanation/speaking - defines the pain severity → patient looks towards their parent (caregiver) to complete her sentence or to answer the question (sharing non-verbal cues to gain confidence)	→ use of different metaphors to describe the pain. → pain or symptoms description is different for patient and caregiver. → patient/caregiver opens their manual logs (pocket diaries) to mention the routine or details of the exercise that patient has been doing. → patient also maintains a manual bar chart of exercises at home for their reflection. (never brought it to the session) → patient also describes different strategies that they are using to ignore or cope with the pain: meditation, doing their favorite activities (e.g., cooking)	→ People then sometimes split into two groups: physio takes the patient for the examination; and the parents meet occupational therapist and other doctors/physio/consultants. → Physio asks the patient to stand up and perform the exercise or lie down on the plinth for the examination.
Examination	→ use of paper based pain scale to understand the pain occurrence and severity in different body parts (ONLY in the first session) → physio does physical examination by pressing different body parts of the body (e.g., checking the pain by folding patient's leg (resting on bed) and pressing the knee) → physio asks the patient to perform some exercises (either old ones or new ones). Physio also asks the pain points and severity associated with every exercise. → physio explains his analysis for every exercise/examination.	→ patient touches their body parts to fill the pain scale (they do not remember it) → Physio educates the patient about the look and feel of different body parts. He also asks the patient to touch his body (e.g., ribs or cage) and then asks to make the comparison with own body. -> Exercises vary a lot. Some of them are performed while lying down on plinth on back or front, doing squats, sitting exercises, tip toes, full body exercises either by standing or lying down on the floor. → While the patient is performing exercise, physio checks the	→ Paper based forms are confusing for the patients - sometimes they do not have pain in a body part at that particular moment AND it is difficult to articulate body pain with different colors or verbally. → For physio, pain scales do not provide sufficient info and thus they do not consider them as an individual entity. The physio always confirms the filled information with the patient. → if the patient (e.g., Lavinia) is bit shy or there are many people in the room, physio also performs the exercise with them to make them more comfortable.	→ Physio asks the patient to take her seat

		patient's hesitation in doing the exercises (e.g., reluctance in bending), facial expressions, body postures (weight distribution, how far the feet are apart), tears in eyes, smoothness in movements, & body tightness (by touching/pressing) → physio checks the body movements carefully and also corrects the patient (if required). → Patient looks at physio while doing exercises to make sure if they are doing okay -- eye gaze		
Diagnosis	→ Physio summarizes his examination (body tightness) → Update on different daily activities/lifestyle of the patient (	→ physio uses hand movements to describe things		physio or caregiver makes the switch
Treatment	→ gives some tips for making active lifestyle and provides education about human body reaction to pain. → Discuss different exercises that patient needs to perform. Patient then sets goals with every exercise: how many repetitions, and how many times a day. → Discussion on other goals such as school attendance	→ uses hand gestures/movements to explain body reaction (e.g., hitting right hand fist on left palm)	→ caregiver takes notes of the exercises that patient has to follow	physio or caregiver makes the switch
Closing	→ Greetings and discussion on next meeting (when to meet and		→ physio marks his digital calendar or writes it on paper	

Alongside the above list, I developed a separate table to list the important bodily cues that were found relevant across different phases of face-to-face consultations. While the above list points to specific incidents from the study sessions, the following table only lists the bodily cues used in those incidents.

Phases	**Bodily Communication during face-to-face**
Waiting	Appearance (clothing, hair style), walking, facial expression
Opening	Posture (cuddling to front), bodily movement (hesitation in sitting down), gaze (eyes down and vocalizing less due to pain)
History Taking	Facial expressions (tears, skin redness), gaze and gestures (head nodding for confirmation and explanation), hesitation in movement and speech, touch (own body)
Examination	Bodily contact (touch, feel, press), physical exercises (stiffness), hesitation, facial expression (eyes closed and stressed), gaze (for confirmation and encouragement)
Diagnosis	Gestures
Treatment	Gestures, physical exercises (summary)
Closing	Gaze

Analysis of Video Consultations

Similar to the above structure, I developed the list of key events that unfolded in video consultations across the following phases: Waiting, Opening, History Taking, Examination, Diagnosis, Treatment and Closing.

Phases	What happens?	Bodily movements & non-verbal cues	Other highlights	How does the phase change?
Waiting	-> happens behind the camera -> both ends prepare their laptop and webcamera -> everyone has already taken up their seats and positions -> patient/caregiver indicates their presence on the s/w: Health Direct (by pressing the Waiting button)	not visible	-> Physio takes around 5-10 minutes in arranging the camera and logging into the system (couldn't recall his password or the procedure to login into the system). Video software also changed 3-4 times within 6 months. This results into a delay (at least 10 minutes) of making the call. → Video s/w changed thrice within 6 months. Although short training (1 day) was offered to the physio., sometimes he was not comfortable in using the new s/w. E.g., when RCH shifted to Health Direct system, physio could not figure out how to make the video call. After trying multiple times for 20-25 minutes, he then shifted to make a telephone call instead. → Physio gets nervous whenever he faces any technical issue and feels embarrassed for the delay in making call (physio feels less control on the technology)	- Physio makes the video call
Opening	→ Starts with checking the technology: audio and video.[[Mark, "Hi! Can you see us?"]] → Most stressful phase for the physio. Checking the technology is the priority:: building rapport comes next. → Making arrangement if there are any technical issues e.g., supplement video call with a telephonic call for audio issues; shifting the video call to a telephonic conversation if the video does not work at all; sharing textual messages for audio issues. → Introduction of who is involved → Follow turn taking: doctor starts → Physio is speaking most of the time: checking the technology or summarizing the last session.	→ when audio does not work, physio uses non-verbal cues such as showing thumb to say great/okay or palm to say wait → People start behaving the same way as that of other end. e.g., if audio does not work at the physio end, patient also remained silent and used gestures to communicate.	-> Usually the session starts late with a delay of 5-10 minutes from physio end. -> Physio apologise multiple times for the delay in making call bcoz of technical issues (if over 15 minutes) → less number of people: physio; patient & caregiver. Sometimes a doctor or occupational therapist joins the physio in the session but the conversation still remains bidirectional (doctor-patient or doctor-caregiver). Mostly the new doctor leaves after their conversation but for 1 session, the occupational therapist stayed for the whole session. → Spatial arrangement: a slight V-shape or side-by-side position at the patient end → Physio makes jokes around the technical issues, "There is a delay of a few seconds at your end. So if I tell you a joke, I have to wait for a while to hear your laughter." → Jokes around technical issues help a lot in making the environment friendly -- for shy/new patients → Types of technical issues: delay in sound at patient end; blurred/pixelated video; audio issue either at one or both end. Every session had one or the other issue. → No feedback of how we look at the other end. The local video is always good as it depends upon the local setup. → Solving technical issue was sometimes very difficult and time taking. e.g., making a telephone call requires the physio to go through extra steps of asking a receptionist to get permission for an external call. → Sometimes the substitute further added more issues, e.g., telephone call adds noise (beep sound), possibly because of the old	→ Physio makes the shift by asking questions, "So Bella, how are things now?"

			telephone; telephone speaker is not loud; loudspeaker does not work. → No understanding of how you look at the other end	
Complaint/ Update	→ Patient/caregiver describes the patient's health condition -- either as a complaint or as an update. → Conversation about the status with recommended exercises, school time table, other daily activities (sleeping, walking etc.)	→ patient/caregiver uses gestures to describe pain. e.g., for stabbing pain, Nikol showed the hand movements. → caregiver touched her body to describe the patient's pain → patient looks at caregiver to complete the sentences (non-verbal cues) → body movements are not always covered because of the camera range	→ takes notes (hand written) → Physio tries to make eye contact all the time. He rarely referred to the digital notes during TC. If he gets engaged in some other activity, e.g., opening a file on computer, he keeps the patient/caregiver informed with what he is doing.	→ Physio makes the shift → Asks the patient to stand and show the exercise.
Examination	→ Cross-questioning about pain: where is the pain, when is the pain severe, (LOCATES scale) → Physio asks the patient to score the pain severity of a scale of 0-10 for different days and different incidents -- multiple scores helps the physio to understand the subjectivity in scoring. [ONLY IN FIRST SESSION] → physio asks the patient to show some exercises, if the patient does not seem to be having a lot of pain. Patient also tells if there is pain while doing the exercise (binary: yes/no) and what are the pain points. → If patient seems to be in terrible pain, physio asks the patient to perform only sitting exercise (make an arch to sideways, press the ribs etc.) → Physio vocalizes a lot to engage the patient with the process	→ physio asks different questions about the pain points by referring/showing his body → patient tries to make eye contacts with the physio to get assurance on the exercises- which is not possible always. → physio looks the patient's facial expression (e.g., stress, closing eyes) while performing exercise to check for pain → Getting qualitative understanding of patient's improvement is bit difficult over video as physio missed the 3D view of the exercise. (e.g., angle of squats, heights). Physio can very well get the cues on smoothness in movement.	→ physio adjusts the camera to show his body parts for reference → patient adjusts the room setup (chairs) and camera to show exercises → Physio gets more understanding of the room arrangement and asks the patient to perform exercises accordingly. → Exercises required the patient to lie down on the bed, stand against the wall, or moving shoulders while sitting. Patients were surprised and reluctant to be asked to show exercises over video. E.g., lying on the bed was bit awkward for Camryn, and she tried to deny but then bargained on the number of repetitions to show. One reason might be that patients do not know what is visible to the other end. → Physio and patient negotiate on how to change their positioning or room/technology arrangement for showing the exercise so that the movement is covered by the camera. E.g., Mark asked Camryn to sit sideways while performing shoulder movements so that he can see Camryn's hand movements more clearly.	→ Physio makes the shift: asks the patient to take their seat.
Diagnosis	→ Physio describes his analysis after seeing the exercises. He talks about the improvements so far and the exercises where the patient needs to work out more. → Physio does not define new issues (diseases) over video. If he couldn't understand the issue, he calls the patient for f2f session.	→ the lack of physical touch and other non-verbal information makes the diagnosis of new disease unsuccessful		→ physio makes the switch
Treatment	→ Physio recommends at most one new exercise if required. The exercise is mostly an easy one e.g., standing exercise against the wall. He does not recommend a completely new exercise as it is difficult to correct the patient's posture in that way. He allows the patient to set the goal with that exercise. → patient shows the new exercise and physio rectifies the body posture, if required. → physio describes the exercise verbally if the video is not working well. → motivation to remain active in daily activities.	→ Physio uses hand gestures/movements to describe the new exercise and to emphasize on special movements (e.g., how to position hand on wall).	→ physio shows the exercise by rearranging the camera positioning, if the video is good. But if the video is not good, he explains it verbally. Even explaining things verbally, physio still shows the movements through different parts thinking that the patient is seeing it (this is because of the lack of feedback of the video on other side)	→ physio makes the switch
Closing	→ discussion on next consultation → Greetings		→ Mark checks his digital calendar to confirm the time for next consultation.	

Alongside the above list, I also developed the following table to list the bodily cues that were available across different phases. This table highlights the comparison with the face-to-face consultations where I striked through those bodily cues that were not used in video consultations.

Phases	Bodily Communication during video consultations
Waiting	~~Appearance (clothing, hair style), walking, facial expression~~ → happens behind the camera
Opening	Posture (cuddling to front), ~~bodily movement (hesitation in sitting down)~~, gaze (eyes down and vocalizing less due to pain)
History Taking	Facial expressions (tears, skin redness), gaze and gestures (head nodding for confirmation and explanation), hesitation in movement and speech, touch (own body)
Examination	~~Bodily contact (touch, feel, press)~~, physical exercises (stiffness), hesitation, facial expression (eyes closed and stressed), gaze (for confirmation and encouragement)
Diagnosis	Gestures
Treatment	Gestures, physical exercises (summary) → very limited exercises
Closing	Gaze

Appendix B
Material for SoPhy Development

Overview: This Appendix provides additional documents to illustrate the development of *SoPhy*. These documents are provided to make the research process transparent and auditable. The listed documents were referred to in Chapter 5 of this thesis. The Appendix contains the following documents:

B.1 presents different designs of the visualisation developed for brainstorming

B.2 shows different templates of the web-interface developed for brainstorming

B.3 provides a summary of all the iterations of the *SoPhy* socks

B.1. Visualisation Templates

This document presents the templates that were showed to the physiotherapist in the last meeting during the development of the *SoPhy*. These templates show different ways to visualise the data captured from different sensors like pressure sensors, flex sensor and accelerometers. The document is referred to in Section 5.4.1 of the thesis.

The following image presents information related to weight distribution from the data captured by the pressure sensors. These designs utilised graphical representation to present the information related to weight distribution in the form of heat maps and circles.

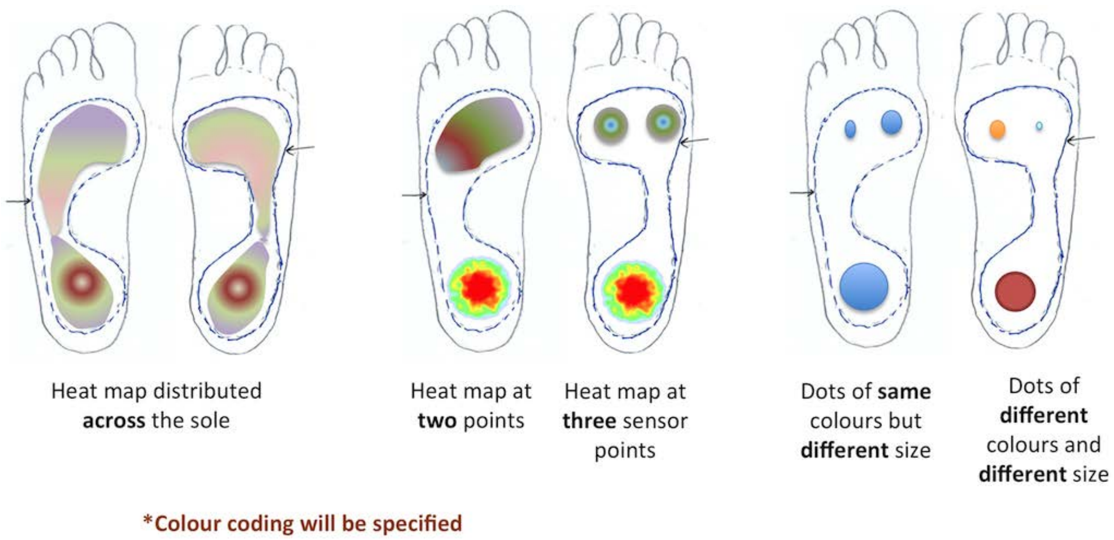


Figure: Possible ways to present information related to weight distribution from the data captured by the pressure sensors.

The following image presents the visualisation related to tremor in leg. The visualisation was created for the data captured from accelerometers. I utilised different number of blue arcs to present the intensity of tremor.

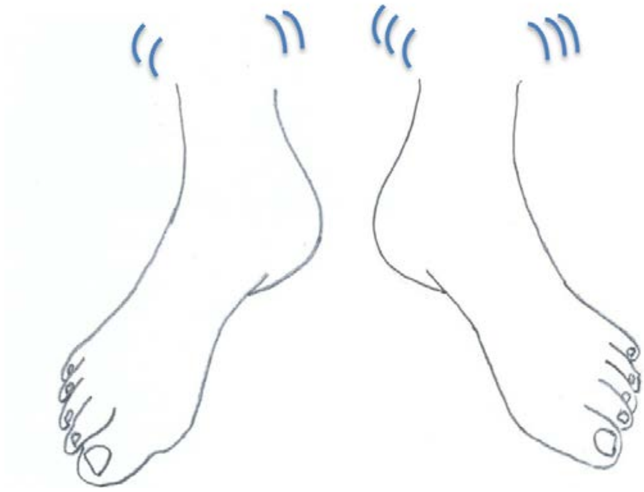
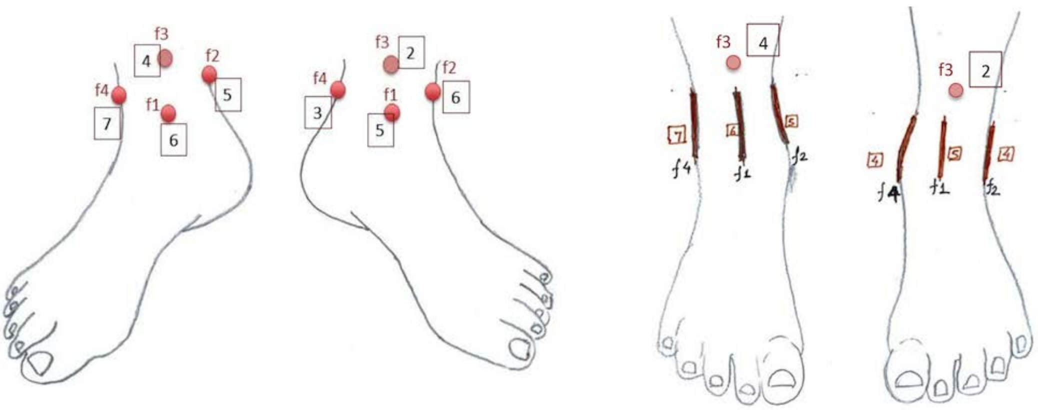


Figure: Possible visualisation of the accelerometer sensor data: The intensity of tremor is denoted through different number of blue arcs.

The following visualisations present information related to foot orientation from the data captured by the flex sensors. The designs utilised dot and line based representations to present flex sensors around the ankle, and presents the sensor data in numbers.



All flexi sensors are represented as **dots** along with the readings

Three flexi sensors are represented as **lines,** and one as a **dot** along with the readings

Figure: Possible ways to present foot orientation through flex sensor data.

The following image presents the visualisation developed by combining the data captured from the flex and pressure sensors. This visualisation was to provide more details on foot orientation, as the numerical representation of the flex sensor data shown above was not sufficient to understand the foot orientation.

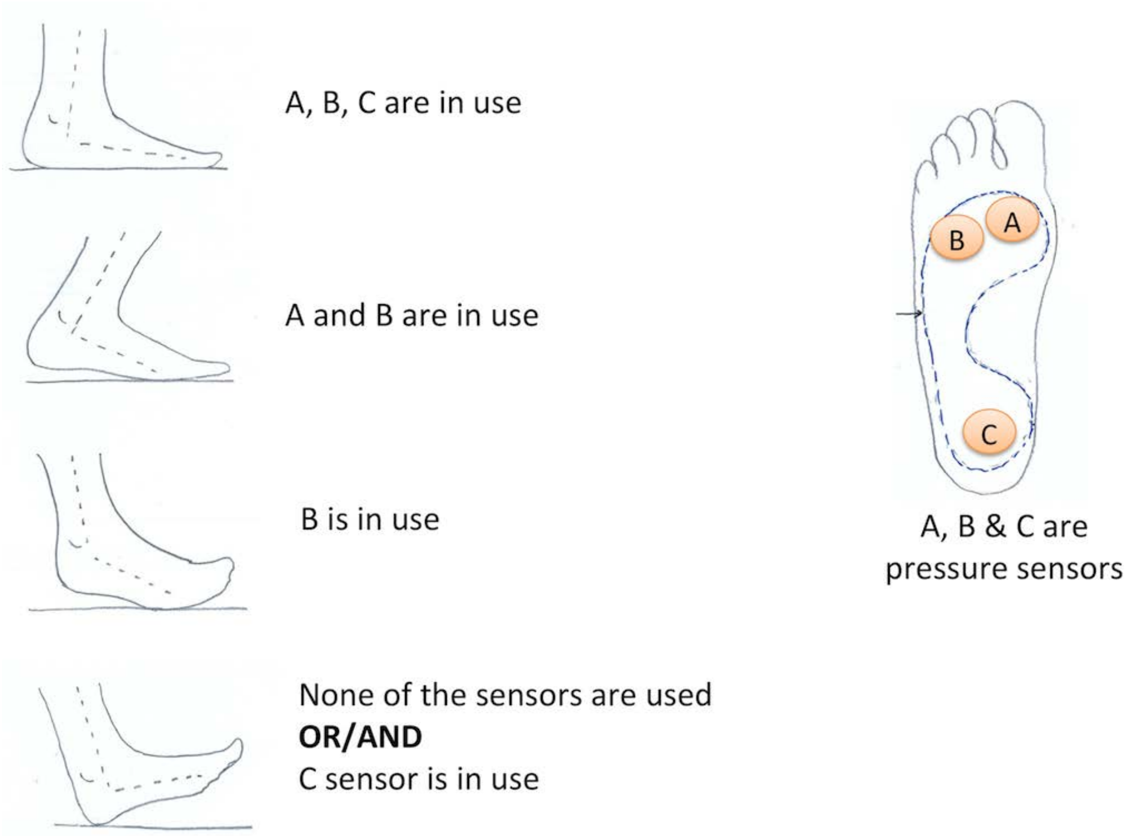


Figure: Possible way to present the information of foot orientation by combining the data from flex and pressure sensors.

B.2. Web-interface Templates

This document presents different templates of the web-interface that were discussed with the physiotherapist during the development process of *SoPhy*. The document is referred to on in Section 5.4.1 in the thesis.

The first design presents all the information from different sensors in a top-down flow. Along with the visualisation, it also provides two functionalities to physiotherapists: Notebook and Canvas. Physiotherapists could take notes and draw sketches of exercises for the patients during video consultations. The physiotherapist appreciated this template as it presented all the information on the same page, with no clicks required.

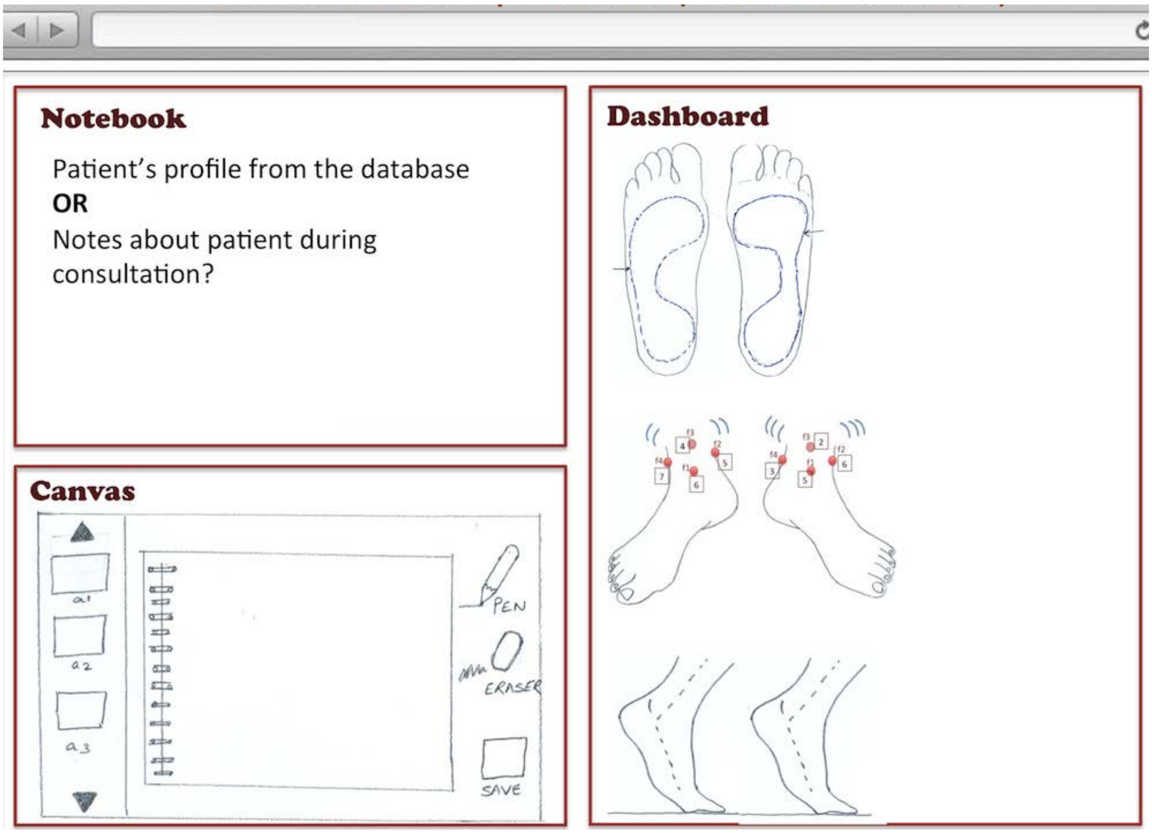


Figure: This design presents all the information with a top-down flow. The page also has the Canvas for the physiotherapist to draw and a Notebook to take notes during video consultations.

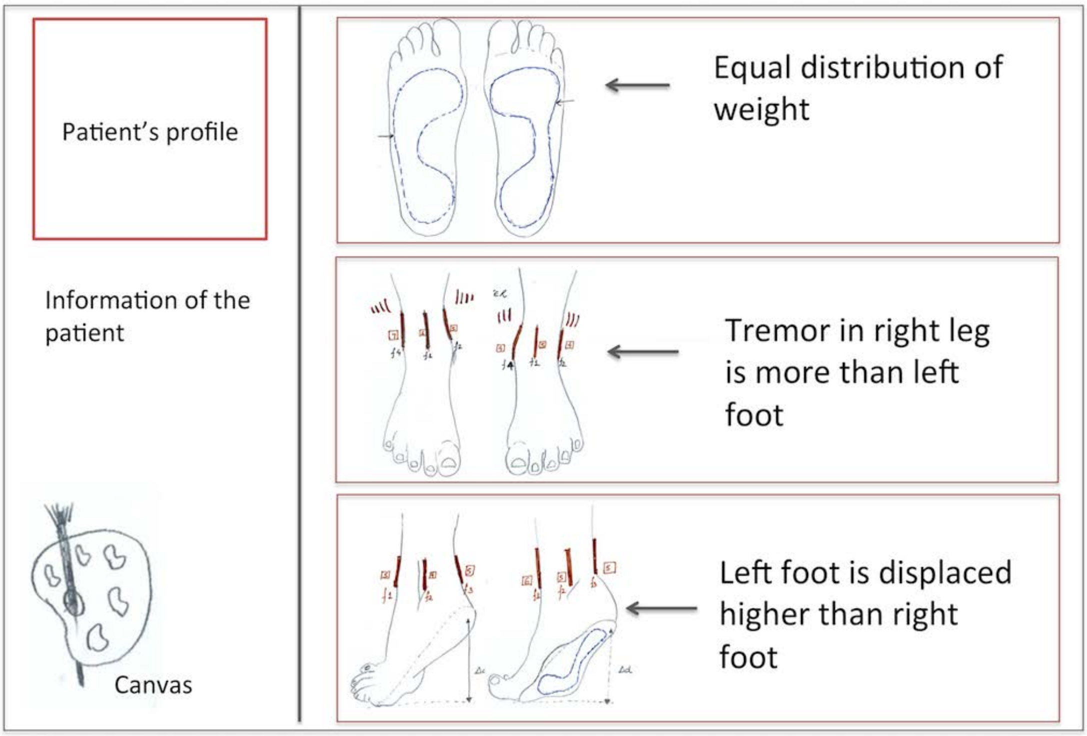


Figure: Another design presents the information of all the sensors on the same page with a top-down flow. The page has a link to the Canvas, where the physiotherapist could draw exercises for the patients during video consultations.

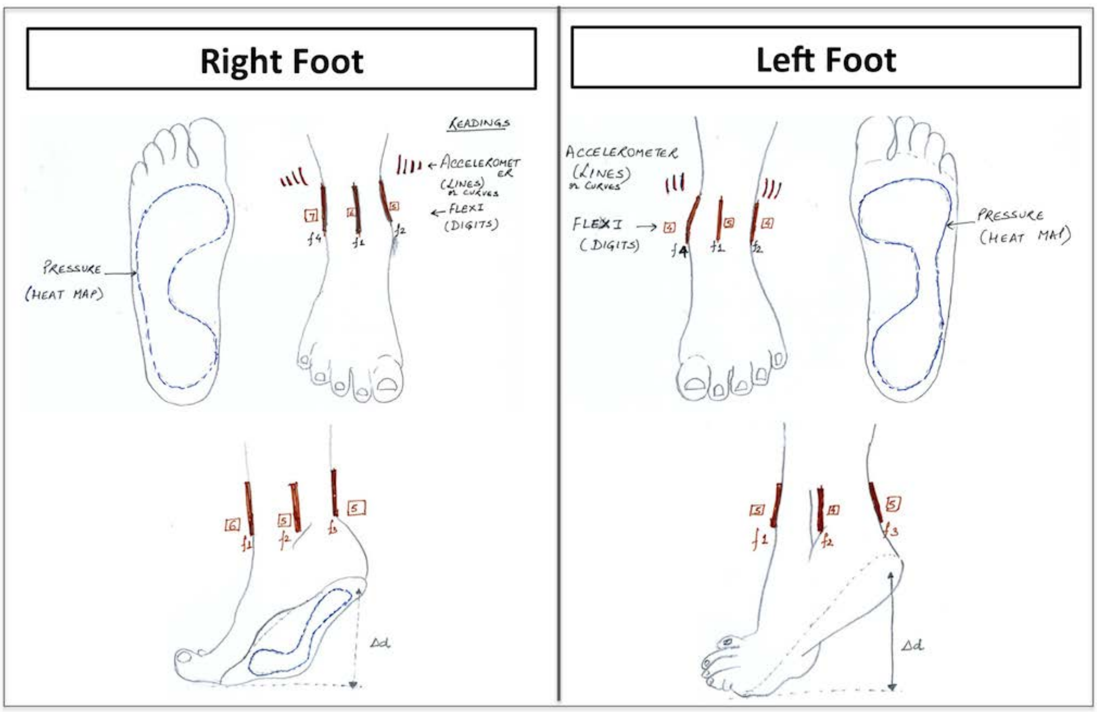


Figure: This design shows the information related to each foot separately.

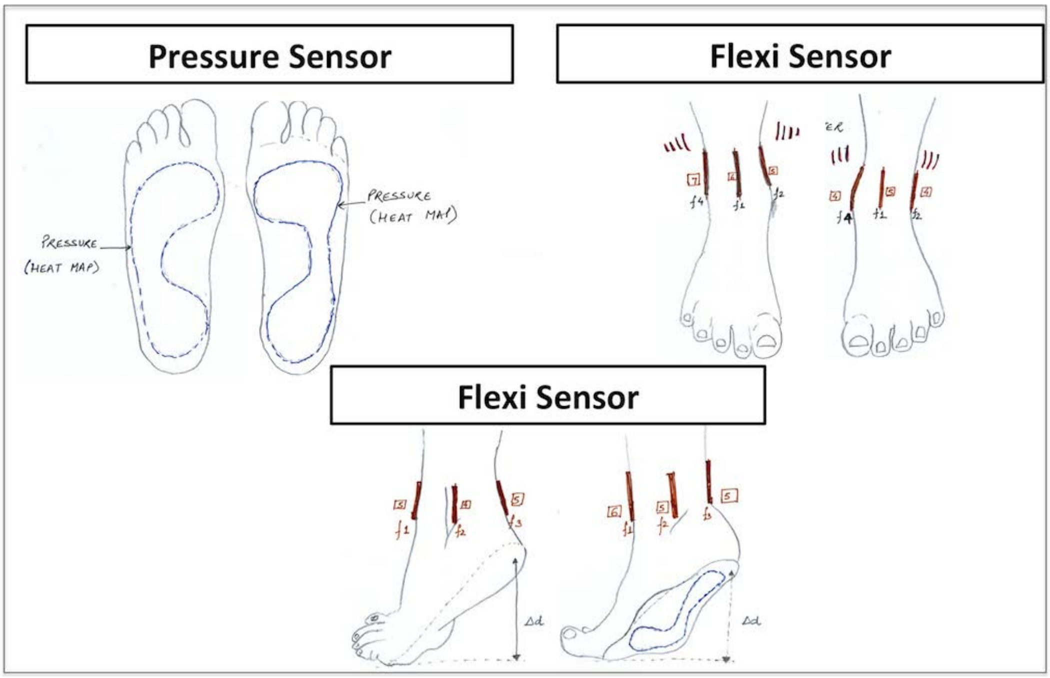


Figure: The final design presents the information of both foot together.

Apart from discussing the design of the web-interface for the clinicians, I also discussed the design of the web-interface at the patient side. For the patient side, I only presented an update on the working of each sensor. However, the physiotherapist suggested to use the same interface at both ends.

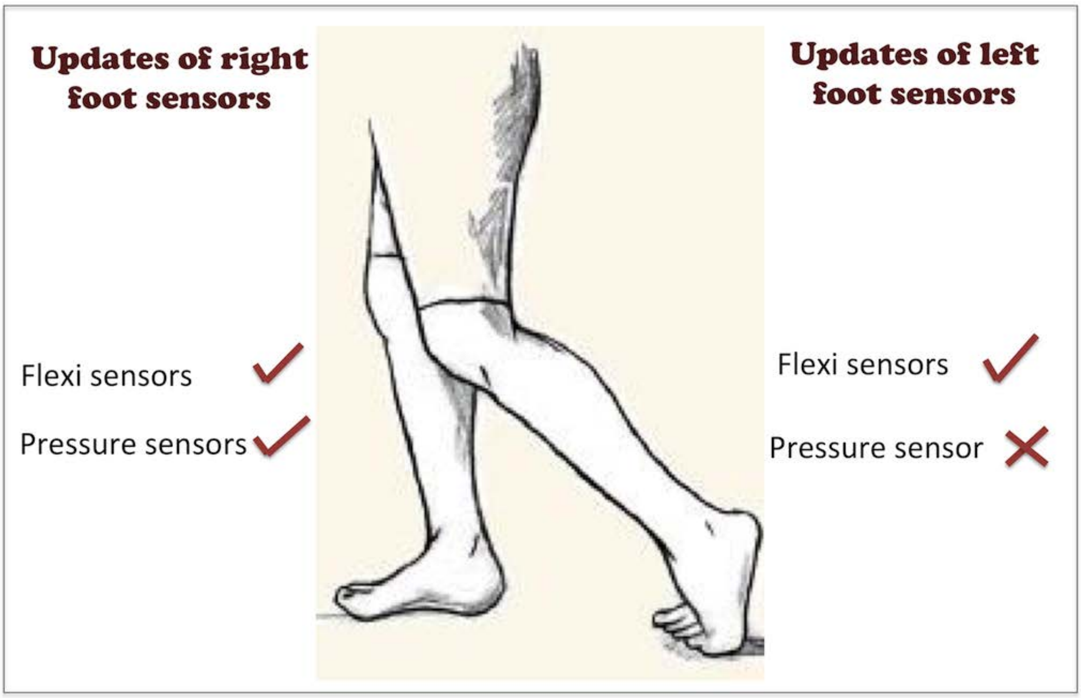


Figure: Web-interface layout for the patient.

B.3. Iterations of the SoPhy Socks

This document provides a summary of the decisions made across different iterations to develop the *SoPhy* socks. The socks went through six iterations and three evaluations with the collaborating physiotherapist. Each iteration involved sock prototyping and lab testing with colleagues from multidisciplinary background. The document is referred to on in Section 5.4.3 of the thesis. The table below lists the steps and outcome at each step of developing the socks.

Iteration (Design form)	**Process**	**Outcome**
0 - Ideation (sketches)	○ Internal discussion ○ Web search on existing systems ○ Web search on different sensors	○ #Pressure sensors: 7 on each foot (5 on toes, 1 on ball and 1 on heel) ○ #Accelerometers: 3 on each leg ○ #Flex sensors: 4 on ankle and 4 on knees ○ #Ultrasonic band: 1 on ankle and 1 on thigh
Meeting 1: Evaluation with the collaborating physiotherapist		
1a - Prototyping (5-toed sock prototype)	○ Sewing was done by filling thermocol beads inside the sock to give it a shape ○ Lilypad was used	○ One 5-toed sock with 4 pressure sensors (1 at big toe and 3 at the sole)
1b - Lab Testing (5-toed sock prototype)	○ Pressure sensors on big toe does not give reading unless pressed very hard ○ Tested with two colleagues: 5-toed socks felt uncomfortable in wearing, and black colour was not appealing ○ Tested the circuit of Flex sensors on breadboard ○ Conductive threads broke while wearing the sock ○ Tested Ultrasonic sensors on breadboard → interference with other sensors	○ Pressure sensors on toes are dropped ○ Drop 5-toed sock → go with regular sock ○ Need more analog pins to accommodate flex sensors → either use two boards or look for another Arduino ○ Stretchable and large size socks is required ○ Drop Ultrasonic sensors

2a - Prototyping (Regular sock prototype)	○ Used stretchable and large size socks for sewing ○ Sewing was done with a large bottle inserted inside the sock (ease in sewing & socks remain stretchable) ○ Arduino Pro-mini was used ○ Sewing issues: short-circuiting around the Arduino board given the small pin holes on the board)	○ One sock with three pressure sensors
2b - Lab Testing (Regular sock prototype)	○ Tested the sock with 2 participants - sock was comfortable to wear ○ Reading of pressure sensor was not correct ○ Tested accelerometers with bread boards → issue of noisy data	○ External attachments on Arduino board were prone to break or get entangled in something else → Robust attachment is required ○ Using the bottle to sew the sock stretched it and dislocated the sensors → look for other alternatives of bottle ○ Use of accelerometers was doubtful
Meeting 2: Evaluation with the collaborating physiotherapist		
Meeting 3: Evaluation with the collaborating physiotherapist		
3a - Prototyping (Regular Sock)	○ Medium size sock sewed with small bottle inserted ○ All pins of Arduino board was soldered with wire extensions ○ Soldered wires provided more space to different paths, and solved the issue of short circuiting ○ Wires were flexible, and thus can be rotated in any direction to make connections with sensors	○ A sock with 3 pressure sensors on sole and 4 flex sensors around ankle
3b - Lab Testing (Regular Sock Prototype)	○ Tested with two colleagues → Soldered wires on Arduino made the sock adjustable on different foot but reduced its aesthetics ○ Range of flex and pressure sensors was not good	○ Try another approach with less wires and more conductive threads

	○ Tested a wide range of resistor values from 11k ohm to 30k ohm for both sensors using alligator clips on the sock → readings were not consistent ○ Tried modular approach for sock: an ankle sock with a band around ankle having flex sensors → readings were not good ○ Tested flex sensors by taping them directly on the ankle (skin) → position matters significantly for correct reading ○ Out of the four flex sensors, two side sensors did not give any reading	○ Use 30k ohm for all sensors - explore ways to get consistent reading of sensors ○ Use valcro tape for flex sensor to adjust its location for different foot ○ Use only front and rear flex sensors
4a - Prototyping (Regular sock)	○ Pressure sensors and flex sensors were sewed using 30k ohm resistor and Arduino board with wire extensions ○ Use of foot mennicken for sewing instead of a bottle to prevent socks from extra stretching ○ The flex sensors were sewed with valcro tape underneath to adjust the positioning according to the foot size	○ A sock with 3 pressure sensors on sole and 2 flex sensors in front and rear of the ankle
4b – Lab Testing (Regular Sock Prototype)	○ Flex sensors were still not sensitive to read foot orientations → tried higher range resistors ○ Pressure sensors values were not consistent ○ Checked tutorials and online forums around resistance and potential difference → issue is in the circuit connections. The connections should be made using the dedicated pins	○ Use only one flex sensor in the front of ankle ○ Correct all the connections to Arduino board
5a - Prototyping (Regular Sock)	○ Three pressure sensors and one flex sensor sewed on a sock using Arduino board with wire extensions ○ The extensions were given spiral shape to improve the aesthetics of the sock	○ A pair of sock with 3 pressure sensors and 1 flex sensor in the front

	○ Rectified all connections, i.e., all ground and positives of the sensors were connected to the dedicated pins on the board	
5b- Lab Testing (Regular Sock Prototype)	○ Tested with four colleagues → comfortable but wires still made the sock look robotic ○ One flex sensor was not sufficient to derive any inference related to range of movement and foot orientation	○ Make the wire extensions hidden to improve its aesthetics ○ Explore other sensors for foot orientation and range of movement
6a – Lab Testing (IMU sensor and breadboard)	○ Replaced flex sensor with IMU- tested it on a breadboard ○ Attached the breadboard on foot to check the location, e.g., front ankle, and bridge of foot	○ IMU sensor worked well and gave a good range of values ○ Appropriate and comfortable position of IMU was at the bridge of the foot
6b – Final Design (Regular sock)	○ Three pressure sensors and 1 IMU sewed on a sock using Arduino board with wire extensions ○ Hide all the extended wires of the Arduino board underneath a cloth	○ A sock with 3 pressure sensors on sole and 1 IMU on the bridge of foot
6c- Lab Testing (Regular sock)	○ All sensors were working fine and all values were consistent	
Developed two pairs of the socks with the final design – one each for medium and large size		

Table : Summary of all six iterations of the *SoPhy* socks.

Appendix C
Material for Study 2

Overview: This Appendix provides additional documents on the data collection and analysis of Study 2. These documents are provided to make the research process transparent and auditable. The listed documents were referred to in Chapter 6 of this thesis. The Appendix contains the following documents:

C.1 presents the plain language description of the project provided to participants

C.2 shows the documents for online recruitment of participants

C.3 lists the script developed to introduce participants to the study tasks

C.4 shows the script developed to guide the actor

C.5 shows the study checklist developed to arrange things before the study session

C.6 lists the observation guide for the study

C.7 presents excerpts from the observation notes diary

C.8 presents the Patient Assessment Form used for data collection

C.9 lists the interview guide for the study

C.10 shows the Sock Wearability Questionnaire

C.11 describes different passes of the data analysis

C.12 shows snippets of the quantitative analysis conducted on the data

C.1. Plain Language Description for Participants

Study 2 required participants to play out two roles - physiotherapists and patient (actor). Therefore, I developed two plain language statement documents for each category. These documents were part of the ethics application approved by the Ethics Advisory Group at the University of Melbourne. The document was printed on the university letterhead. This document was referred to in Section 6.2. Below I present the plain language description that was provided to participants who acted as physiotherapists.

Plain Language Statement (Participants)

THE UNIVERSITY OF MELBOURNE

Project Title: SmartSox: A Lab based Evaluation of Wearable Technology for Video Consultations

Investigators: Deepti Aggarwal, Bernd Ploderer, Thuong Hoang, Frank Vetere,
Department of Computing and Information Systems, University of Melbourne

Mark Bradford
Royal Children's Hospital, Melbourne

Purpose of the Study

The purpose of this research is to enhance video-based consultations through SmartSox, a technology designed to help physiotherapists monitor leg exercises. SmartSox consists of different sensors embedded on the sole and around ankle of a sock. These sensors monitor pressure and movement when worn during exercise. This information is visualized in real-time to provide physiotherapists with detailed insights into patient's movements during video-based consultations.

Your participation in this study will help to evaluate the overall usefulness of SmartSox for physiotherapists. In a lab-based environment that simulates a real-time video consultation, you will try out the SmartSox and provide feedback through an interview and two questionnaires.

This project will form a part of Deepti Aggarwal's PhD research, and has been approved by the Human Research Ethics Committee (HREC) at the University of Melbourne.

Who can participate?

We are looking for adults (over the age of 18 years) who are studying in the final year of Physiotherapy.

What will I be asked to do?
You will be asked to take part in a laboratory study to (1) trial SmartSox in a simulated video consultation and (2) to comment on SmartSox through an interview.

The trial will consist of two simulated real-time video consultations for physiotherapy with a mock patient. You will guide the patient to perform a set of exercises and assess his/her movements over video, once with the SmartSox system and once without it. You will be asked to provide feedback via a questionnaire.

During the interview you will be asked to comment on the clarity and usefulness of the data visualisations. You will also be asked to wear the socks with embedded sensors and to comment on the comfort of wearing the technology.

The trial and the interview combined will last no longer than 60 minutes. Both activities will take place in the Interaction Design Lab in the Doug McDonell Building at the University of Melbourne, Parkville. The study will be video recorded for later analysis.

What are the benefits of me participating?
You will have an opportunity to try out novel sensor technology and contribute to its design to help clinicians and patients communicate more effectively over-a-distance. You will receive a $20 voucher for your participation.

Will participation prejudice me in any way?
Your participation in this study is completely voluntary. You are free to withdraw at any time without explanation, and to withdraw any unprocessed data that you have supplied.

How will my confidentiality be protected?
We intend to protect your anonymity and the confidentiality of your responses to the fullest extent, within the limits of law. Your name and contact details will be kept in a separate, password-protected computer file from any data that you supply. In the final report, you will be referred to by a pseudonym. We will remove any references to personal information that might allow someone to guess your identity; however, you should note that as the number of people we seek to interview is very small, it is possible that someone may still be able to identify you. The data will be kept securely at the university for five years from the date of publication, before being destroyed.

How can I receive feedback on the research findings?
You can indicate on the consent form if you wish to receive a brief summary of the research findings and copies of any papers arising from this research via email.

From where can I get further Information?
Should you require any further information, or have any concerns, please do not hesitate to contact either of the researchers listed below:

- Deepti Aggarwal (daggarwal@student.unimelb.edu.au, 04 7007 3052)
- Dr. Bernd Ploderer (ploderer@unimelb.edu.au, 07 3138 4927)
- Dr. Thuong Hoang (thuong.hoang@unimelb.edu.au, 03 8344 3419)
- Prof. Frank Vetere (f.vetere@unimelb.edu.au, 03 8344 1496)
- Dr. Mark Bradford (mark.bradford@rch.org.au, 04 2198 4090)

This research project has been approved by the Human Research Ethics Committee of the University of Melbourne. If you have any concerns or complaints about the conduct of this research project, which you do not want to discuss with the research team, you should contact the Manager, Human Research Ethics and Integrity, University of Melbourne, VIC 3010. Tel: +61 3 8344 2073 or Fax: +61 3 9347 6739 or email: HumanEthicscomplaints@unimelb.edu.au. All complaints will be treated confidentially. In any correspondence, please provide the name of the research team or the name or ethics ID number of the research project.

How do I agree to participate?
If you would like to participate, please get in contact with Deepti Aggarwal (047 007 3052, daggarwal@student.unimelb.edu.au) to arrange a mutually convenient time to take part in this study. At the meeting you will also have to indicate that you have read and understood this information by signing the accompanying consent form.

Thank you for your help.

Department of Computing and Information Systems
The University of Melbourne, Victoria 3010 Australia
T: +61 3 8344 1501 **F:** +61 3 9349 4596
W: www.cis.unimelb.edu.au

The following document provides the plain language description of the project that was provided to the actor in Study 2. It was part of the ethics application approved by the Ethics Advisory Group at the University of Melbourne. The document was printed on the university letterhead.

THE UNIVERSITY OF MELBOURNE

Plain Language Statement (Actor)

Project Title: SmartSox: A Lab based Evaluation of Wearable Technology for Video Consultations

Investigators: Deepti Aggarwal, Bernd Ploderer, Thuong Hoang, Frank Vetere,
Department of Computing and Information Systems, University of Melbourne

Mark Bradford
Royal Children's Hospital, Melbourne

Purpose of the Study
The purpose of this research is to enhance video-based consultations through SmartSox, a technology designed to help physiotherapists monitor leg exercises. SmartSox consists of different sensors embedded on the sole and around ankle of a sock. These sensors monitor pressure and movement when worn during exercise. This information is visualized in real-time to provide physiotherapists with detailed insights into patient's movements during video-based consultations.

Your participation in this study will help to evaluate the overall usefulness of SmartSox for physiotherapists. In a lab-based environment that simulates a real-time video consultation, you will try out the SmartSox by wearing it in your feet.

This project will form a part of Deepti Aggarwal's PhD research, and has been approved by the Human Research Ethics Committee (HREC) at the University of Melbourne.

Who can participate?
We are looking for adults (over the age of 18 years) who are studying in the final year of Physiotherapy.

What will I be asked to do?
You will be asked to take part in a laboratory study on evaluating SmartSox with 20 trials of simulated video consultations.

Each trial consists of two simulated real-time video consultations with physiotherapist – one with SmartSox and one without it. Your participation requires wearing SmartSox on feet and performing exercises as guided by the clinician over video. You will act as a patient in these simulated sessions and perform a set of 5 lower body exercises. For instance, you will perform exercises like squats and tip-toes over video, once with the SmartSox system and once without it.

Each trial will last no longer than 30 minutes. The study will take place in the Interaction Design Lab in the Doug McDonell Building at the University of Melbourne, Parkville.

What are the benefits of me participating?
You will have an opportunity to try out novel sensor technology and contribute to its design to help clinicians and patients communicate more effectively over-a-distance. You will be paid $400 for your participation.

Will participation prejudice me in any way?
Your participation in this study is completely voluntary. You are free to withdraw at any time without explanation, and to withdraw any unprocessed data that you have supplied.

How will my confidentiality be protected?
We intend to protect your anonymity and the confidentiality of your responses to the fullest extent, within the limits of law. Your name and contact details will be kept in a separate, password-protected computer file from any data that you supply. In the final report, you will be referred to by a pseudonym. We will remove any references to personal information that might allow someone to guess your identity. The data will be kept securely at the university for five years from the date of publication, before being destroyed.

How can I receive feedback on the research findings?
You can indicate on the consent form if you wish to receive a brief summary of the research findings and copies of any papers arising from this research via email.

From where can I get further Information?
Should you require any further information, or have any concerns, please do not hesitate to contact either of the researchers listed below:

- Deepti Aggarwal (daggarwal@student.unimelb.edu.au, 04 7007 3052)
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- Dr. Thuong Hoang (thuong.hoang@unimelb.edu.au, 03 8344 3419)
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How do I agree to participate?
If you would like to participate, please get in contact with Deepti Aggarwal (047 007 3052, daggarwal@student.unimelb.edu.au) to arrange a mutually convenient time to take part in this study. At the meeting you will also have to indicate that you have read and understood this information by signing the accompanying consent form.

Thank you for your help.

Department of Computing and Information Systems
The University of Melbourne, Victoria 3010 Australia
T: +61 3 8344 1501 **F:** +61 3 9349 4596
W: www.cis.unimelb.edu.au

C.2. Online Recruitment of Participants

Participants for Study 2 were recruited from the university's mailing list of postgraduate physiotherapy students. I sent the email invitation to a professor at the physiotherapy department who forwarded it in the relevant mailing list. The email advertisement included a brief description of the study with my contact details. It also had the website address, where more information of the study was available. This document was part of the ethics application approved by the Ethics Advisory Group at the University of Melbourne (HREC Reference #1646826). The document is referred to in Section 6.3.1 in the thesis. Below is the draft of the email advertisement.

Project Title: SmartSox: A Lab based Evaluation of Wearable Technology for Video Consultations

Investigators: Deepti Aggarwal, Bernd Ploderer, Thuong Hoang, Frank Vetere, Mark Bradford

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The following message will be emailed out to students of physiotherapy via the university emailing list:

Physiotherapists needed to evaluate visualisations of movement data from a wearable technology

Researchers at the University of Melbourne (Dept. of Computing and Information Systems) are building a wearable technology that aims to support lower body rehabilitation during video consultations for physiotherapy. We are looking for final year physiotherapy students to evaluate the utility of the developed technology through a laboratory study (lasting 30 minutes) followed by an interview (lasting 30 minutes). Volunteers will receive a $20 voucher. HREC# 1646826

Enquiries: Deepti Aggarwal, 04 7007 3052, daggarwal@student.unimelb.edu.au, http://deeptiaggarwal.com/call-for-participants.html

Physiotherapist needed to trial a wearable technology designed to track leg movements

Researchers at the University of Melbourne (Dept. of Computing and Information Systems) are building a wearable technology that aims to support lower body rehabilitation during video consultations for physiotherapy. We are looking for one final year physiotherapy student who can act as a patient in a laboratory evaluation of the developed technology. The study consists of 20 trials in total, with each trial lasting 30 minutes. The participant will be paid $400 for study participation. HREC# 1646826

Enquiries: Deepti Aggarwal, 04 7007 3052, daggarwal@student.unimelb.edu.au, http://deeptiaggarwal.com/call-for-actor.html

Email Advertisement; Version 2; 24 May 2016; HREC Reference #1646826

Below I provide snapshots of the website providing details on the study aims and the study tasks. Since the study involved two categories of participants - physiotherapists and patient (actor), I developed two websites explaining participation for each category. These websites had links to the plain language statement and consent form and provided my contact details together with the University of Melbourne's Human Research Ethics Committee. The webpages were online for the entire duration of the study on my homepage - http://deeptiaggarwal.com.

MORE INFORMATION

Plain Language Statement (pdf)
Consent form (pdf)
Call for participants

Try out Technology for Video Consultations

In this research project, we are developing a wearable technology for video consultations that can help physiotherapists in assessing patients' movements over video.

We are looking for **one final year physiotherapy student** who can trial the wearable technology in a laboratory study. In a lab-based environment that simulates a real-time video consultation, you will try out the technology by wearing it in your feet. The study consists of **20 sessions, with each session lasting 30 minutes. The study will run for 1-2 weeks with 2-4 sessions conducted each day.** Participant will be paid $400 for participation.

The technology monitors lower body movements through different sensors embedded on the sole and around ankle of a sock. These sensors monitor pressure and orientation related information, when worn during exercise. The captured information is visualized in real-time to provide physiotherapists with detailed insights into patient's movements during video-based consultations.

Contact Deepti Aggarwal on daggarwal[@]student.unimelb.edu.au for more information or to indicate your interest.

What will I be asked to do?

You will be asked to take part in a laboratory study on evaluating the technology with 20 trials of simulated video consultations.

Each trial consists of two simulated real-time video consultations with a physiotherapist - one with the technology and one without it. Your participation requires wearing the socks on feet and performing exercises as guided by the physiotherapist over video. You will act as a patient in these simulated sessions and perform a set of 5 lower body exercises. For example, you will perform squats and tip-toes over video, once with the developed technology and once without it.

Each trial will last no longer than 30 minutes. The study will take place in the Interaction Design Lab in the Doug McDonell Building at the University of Melbourne, Parkville.

What are the benefits of me participating?

You will have an opportunity to try out a novel sensor technology and contribute to its design. Your feedback will help us in developing technology that can make video consultations effective for conducting remote lower body physiotherapy. You will also be paid $400 for your participation.

How can I sign up and get access to the wearable technology?

To indicate your interest, contact Deepti Aggarwal (daggarwal[@]student.unimelb.edu.au), providing your phone number or email address. We will contact you to check your eligibility and to schedule a time for study.

Where can I get further information?

Further information about this study is included in the plain language statement and the consent form. (The researchers will have a paper copy of these documents available for you during the trial.)

This research project has been approved by the Human Research Ethics Committee **(HREC Reference #1646826)** of the University of Melbourne. If you have any concerns or complaints about the conduct of this research project, which you do not want to discuss with the research team, you should contact the Manager, Human Research Ethics and Integrity, University of Melbourne, VIC 3010. Tel: +61 3 8344 2073 or Fax: +61 3 9347 6739 or email: HumanEthicscomplaints@unimelb.edu.au. All complaints will be treated confidentially. In any correspondence, please provide the name of the research team or the name or ethics ID number of the research project.

Figure : Snapshot of the webpage describing the call for an actor.

MORE INFORMATION

Plain Language Statement (pdf)

Consent form (pdf)

Call for actor

Laboratory Evaluation of a Technology for Video Consultations

In this research project, we are developing a wearable technology for video consultations that can help physiotherapists in assessing patients' movements over video.

We are looking for **final year physiotherapy students** who can trial the wearable technology in a laboratory study. In a lab-based environment that simulates a real-time video consultation, you will evaluate the overall usefulness of the developed technology and provide feedback through an interview and two questionnaires. **Participation in study** will approximately take **60 minutes**. Volunteers will receive a $20 voucher as a token of appreciation for their participation.

The technology monitors lower body movements through different sensors embedded on the sole and around ankle of a sock. These sensors monitor pressure and orientation related information, when worn during exercise. The captured information is visualized in real-time to provide physiotherapists with detailed insights into patient's movements during video-based consultations.

Contact Deepti Aggarwal on daggarwal[@]student.unimelb.edu.au for more information or to indicate your interest.

What will I be asked to do?

You will be asked to take part in a laboratory study to (1) trial the developed technology in a simulated video consultation and (2) to comment on the technology through an interview.

The trial will consist of two simulated real-time video consultations for physiotherapy with a mock patient. You will guide the patient to perform a set of exercises and assess his/her movements over video, once with the technology and once without it. You will be asked to provide feedback via a questionnaire.

During the interview, you will be asked to comment on the clarity and usefulness of the data visualisations. You will also be asked to wear the socks with embedded sensors and to comment on the comfort of wearing it.

The trial and the interview combined will last no longer than 60 minutes. You will receive a $20 voucher for your participation. Both activities will take place in the Interaction Design Lab in the Doug McDonell Building at the University of Melbourne, Parkville. The study will be video recorded for later analysis.

What are the benefits of me participating?

You will have an opportunity to try out a novel sensor technology and contribute to its design. Your feedback will help us in developing technology that can make video consultations effective for conducting remote lower body physiotherapy.

How can I sign up and get access to the wearable technology?

To indicate your interest, contact Deepti Aggarwal (daggarwal[@]student.unimelb.edu.au), providing your phone number or email address. We will contact you to check your eligibility and to schedule a time for study.

Where can I get further information?

Further information about this study is included in the plain language statement and the consent form. (The researchers will have a paper copy of these documents available for you during the trial.)

This research project has been approved by the Human Research Ethics Committee **HREC Reference #1646826)** of the University of Melbourne. If you have any concerns or complaints about the conduct of this research project, which you do not want to discuss with the research team, you should contact the Manager, Human Research Ethics and Integrity, University of Melbourne, VIC 3010. Tel: +61 3 8344 2073 or Fax: +61 3 9347 6739 or email: HumanEthicscomplaints@unimelb.edu.au. All complaints will be treated confidentially. In any correspondence, please provide the name of the research team or the name or ethics ID number of the research project.

Figure : Snapshot of the webpage describing the call for participants.

C.3. Script for Participants

To explain participants the study tasks, I developed the following document. This document provides a step-wise explanation of the study tasks with a flow chart of what participants were expected to do in each session. While walking through this guide, I also introduced the Patient Assessment Form to the participants. At the end of this guide, participants signed the consent form. This document is referred to in Section 6.3.2 of the thesis.

Study Guide for Clinicians

1. The study

This project aims to support the work of physiotherapists during video consultations. We have developed an interactive pair of socks that captures information related to patient's movements and communicate it to the physiotherapist in real-time. The socks captures weight distribution, range of movement, and orientation of foot when the patient is doing exercise. The physiotherapist, on their end, sees the captured information on a webpage. Through this study, we aim to evaluate how the developed socks help physiotherapists in making their assessment during video consultations.

2. Being the physiotherapist

You will be acting as a physiotherapist in this study. Imagine that you are a physiotherapist based in Melbourne. You have four patients who are living in other parts of Australia. Today, you are organising follow-up consultations with them via Skype.

3. Number of video sessions

You will make four video consultations today via Skype. Out of the four sessions, the two sessions include the patient wearing the developed socks. For these sessions, you will have a webpage opened on the other screen along with the Skype call. The webpage provides the real-time information related to the patient's movements as captured by the socks.

4. Meeting your patients

You will meet four patients today. Out of these four, two patients are suffering with chronic pain in left foot, and the other two are going through rehabilitation in right foot. You have already had a couple of face-to-face consultations with all of them.

5. Assessing the patient's movements

In each session, you will assess the patient's recovery with the following exercises: dorsiflexion and plantar flexion; squats; double leg heel raises, and single leg heel raises. These are the exercises that you have recommended to each patient in the last consultation in face-to-face setting.

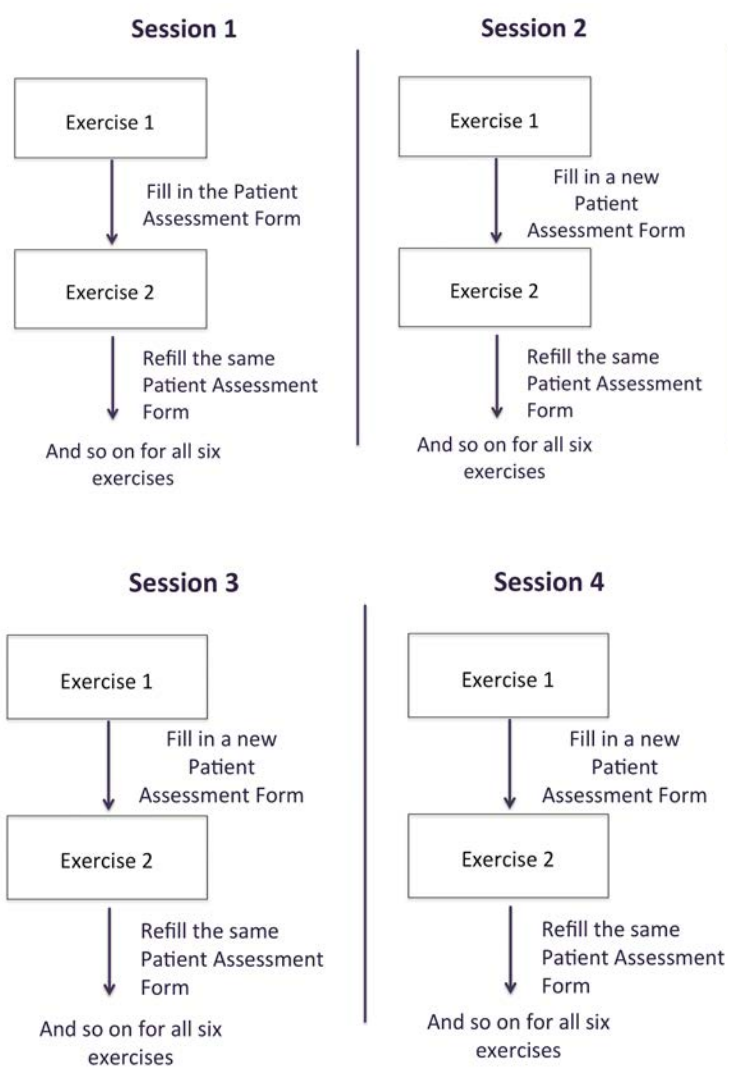
6. Logging the assessment

For all 4 patients, you will write your assessment related to each exercise in the' Patient Assessment Form'. The Patient Assessment Form is a guide for you to take notes related to the patient's condition. It has 6 pages: the first page provides a brief information of the patient you are seeing along with some details to fill in the beginning of the consultation. In the next four pages, you are required to fill in details related to each exercise during the session, as you continue with the exercises. Finally, on the last page, you will provide your overall assessment of the patient's condition - you can fill this page towards the end of the session or after the session is over.

7. Post session

After the four video sessions, I will conduct a semi-structured interview with you to understand your overall experience. During the interview, you will also be asked to try out the socks and complete the sock wearability questionnaire.

Flow of the sessions



C.4. Actor Script

This document provides a snapshot of the script provided to the actor to guide her performance in the study. The script described four patient profiles - two each for extreme pain and low pain. Below I provide snapshots of the two patient profiles corresponding to the extreme pain condition to illustrate the difference between the information provided to the actor for *with SoPhy* and *without SoPhy* conditions. In these profiles, patients were given different background but they had the same physical and emotional conditions (listed in the blue box). The actor received the similar information for low pain patient profiles. This document is referred to in Section 6.3.2 of the thesis.

Patient Profile 1 #1

NAME Veena Baker

YOUR PROFILE

You are Veena a 15-year-old, high school girl. Your hobbies include horse riding and playing football. You were very active in sports until 2 years back when you **twisted your left ankle** while playing football.

After the incident, you started to have pain in left foot with extreme pain around ankle. You have been on medication for 4 months and have consulted a psychiatrist and a surgeon thus far. You preferred not to have any surgery and have recently started physiotherapy to get rid of your pain. You are diagnosed with chronic pain in left foot ankle.

In the last 2 months, you have had 3 face-to-face consultations with your physiotherapist. And in the last consultation, your physiotherapist suggested you to perform 4 exercises twice a day with 5 repetitions each time. The exercises include dorsiflexion and plantar flexion, squats, Double leg heel raises, and single leg heel raises.

Here are the highlights of your condition:

Living with parents, both working and have a busy schedule

Walking – asymmetric with more weight on toes of left foot
Fearful of walking and touching
Constant pain
Swelling in ankle and outside of foot
Feeling helpless
Skipping school
Isolated from friend circle - stopped going in social events

Pain scale rating: 6 (scale of 0 to 6) (HIGH PAIN)

Current activities - reading, watching TV
Avoiding walking and movements

Today you are again having extreme pain in left ankle, so much that you are avoiding any movements. You are meeting with your physiotherapist over video.

Patient Profile 1 (SoPhy condition) #2

NAME Sam Green

YOUR PROFILE

You are Sam, a 16-year-old girl, working as a chef in a restaurant. Your hobbies include cooking and painting. Last year, you **twisted your left foot** during a busy day at the restaurant.

After the incident, you feel pain around ankle. The pain is not constant, but on days when you have it, it gets unbearable. You have consulted many clinicians thus far, but the pain does not seem to go away. You have recently met a physiotherapist based in Melbourne to get rid of your pain.

In last 2 months, you have had 5 face-to-face consultations with your physiotherapist. In the last consultation, your physiotherapist suggested you to perform 4 exercises twice a day with 5 repetitions each time. The exercises include dorsiflexion and plantar flexion, squats, Double leg heel raises, and single leg heel raises.

Here are the highlights of your condition:

Living with parents, both working and have a busy schedule

Walking – asymmetric with more weight on toes of left foot
Fearful of walking and touching
Constant pain
Swelling in ankle and outside of foot
Feeling helpless
Skipping school
Isolated from friend circle - stopped going in social events

Pain scale rating: 6 (scale of 0 to 6) (HIGH PAIN)

Current activities - reading, watching TV
Avoiding walking and movements

Today you are again having extreme pain in left ankle, so much that you are avoiding any movements. You are meeting with your physiotherapist over video.

C.5. Study Checklist

I developed a checklist of the tasks that I was required to accomplish to conduct a study session. The list included tasks from a day prior to the study session to the activities after the end of the session. This list served me as a reminder to prepare the venue for the study sessions. This document is referred to in Section 6.3.3 of the thesis.

One day before session

1. Send reminder email to the participants
2. Charge the cameras
3. Charge the phones
4. Charge the laptops

Before Session

1. Print the documents

- Checklist
- Consent form for both patient (only once) and participant -- **colored**
- Plain Language statement or both patient (only once) and participant -- **colored**
- Questionnaire of sock wearability -- **colored**
- 4 sets of Patient assessment form -- **colored**
- Questionnaire on sock wearability **-- colored**
- Interview guide, particularly, photographs of the visualisation -- **colored**
- Observation guide (black n white)
- Clinician script (colored)

2. Prepare the documents

- Update the 'Participant details' google doc with the participant id and details
- Prepare the 4 sets of assessment form: put the participant id & session sequence (each page of the set is loose to allow flexibility to the clinician)
- Arrange the 4 profiles according to the sequence for the patient
    - add a sticky note on the profile which require the patient to wear socks
- Prepare the questionnaire on sock wearability with participant id

3. Preparation for data collection

- Two cameras in both rooms
    - check the battery
    - storage space
- 1 laptop/phone to record interview (use QuickTime player if using Mac)

4. Collect the vouchers to give away

5. Stationary

- Loose papers and pen
- One notebook and pen to take observation notes

6. Bring snacks

7. Preparing the socks

- Bring the small socks to wear inside
- 2 phones for bluetooth connection
    - Check the battery of phones
    - Restart the phone beforehand to avoid any issue
    - Reinstall the mobile app (if any issue)
- bring both pairs
- Bluetooth devices for the socks
- 2 batteries
    - Charge them
    - Bring the charger

8. Setting up the rooms

- Place two screens in both rooms
- Place 1 webcam in both rooms
- Skype
    - Login with Skype accounts in each room
    - Make one skype call to check the audio and video
- Set the webcam of the patient to capture her full body
- Set up the laptop in the patient room
- Open the webpage of Smartsox on the second screen in clinician's room (via localhost login)
- Position the tripod and camera for recording
- Place a notebook and pen in each room
- Place some snacks, water/juice/coffee for the actor
- Place 4 patient profile documents in the patient room - according to the sequence of the study session
- Place 4 sets of assessment form in the clinician room (as per the sequence)

9. Arrival of the patient

- Actor will come 15 minutes before the scheduled time of the session
- Ask her if she needs water/coffee
- Take her signature on the consent form (ONLY IN FIRST SESSION)
- Give a copy of the PLS
- Instructions:
    - If there is no other session, she can leave after 5-10 minutes after the session is over.
    - Do not change the webcam positioning

        - After a session is over, move to the other profile. The sequence of 4 profiles will change every day - the sequence of documents will change accordingly.
        - Wear the socks when the document has a sticky note with ‘wear socks’ tag
        - Wear the small socks first before wearing the socks

10. Arrival of the clinician

- Invite the participant directly in the clinician room
- Introduce myself
- Ask details of the participant → update the ‘Participant details’ form (age, gender, year)
- Introduce the participant to the study through Clinician’s script.
- Mention that I will be sitting in with the participant
- Show the assessment forms -- give the first set based on the sequence
- Give one copy of the PLS
- Take signature on the consent form

11. Beginning of the session

- participant sets the Assessment form, as per their needs (loose, spreaded)
- participant makes the Skype call

12. During the session

- participant asks the patient to perform each exercise one-by-one
- Participant fills the assessment form
- Take photographs of both sides

13. In between the sessions

- 5 minutes of break
- Clinician
    - Give the new assessment form to the clinician
    - Walk through the new patient profile via the assessment form
    - Open the webpage of the smartsocks on the other screen for session with socks
- Patient
    - Ask the patient to move to the other profile
    - Actor wears the socks based on the sequence

14. Post sessions

- Actor leaves after 5-10 minutes if there is no other session afterwards
- Interview with the participant
    - Use the copy of interview guide to show visualisations
- Give 1 pair of socks for trial (ask to wear)
- Ask the participant to fill the questionnaire on sock wearability

15. Ending

- Thank the participant

- Give the voucher

After each study session

1. Check the questionnaire and assessment forms for participant id and session - populate the data in the excel sheet
2. Write a summary of the interview - mark the key points
3. Look at the field notes - mark the key points
4. Take the back up of the data collected from
    - camera recordings
    - interview recordings

C.6. Observation Guide

The following document lists the observation guide that I used to take notes during the study. The observation guide was a part of the ethics application approved by the Ethics Advisory Group at the University of Melbourne. Here, I present the observation guide prepared at the start of the study. I refined this guide throughout the study as my understanding of the research problem and the context developed over time. This document was referred to in Section 6.3.4 in this thesis.

The aim of these observations was to understand their interaction with the interface (visualisations) and the limitations of the current design. Following are a set of sample questions that guide my observations.

Understanding participant interactions with interface

1. How is the screen organized?
2. When do participants refer to the interface?
3. How do they read the visualisations presented on interface?
4. When do participants use 'Canvas'?
5. What do they draw using Canvas?

Understanding the process

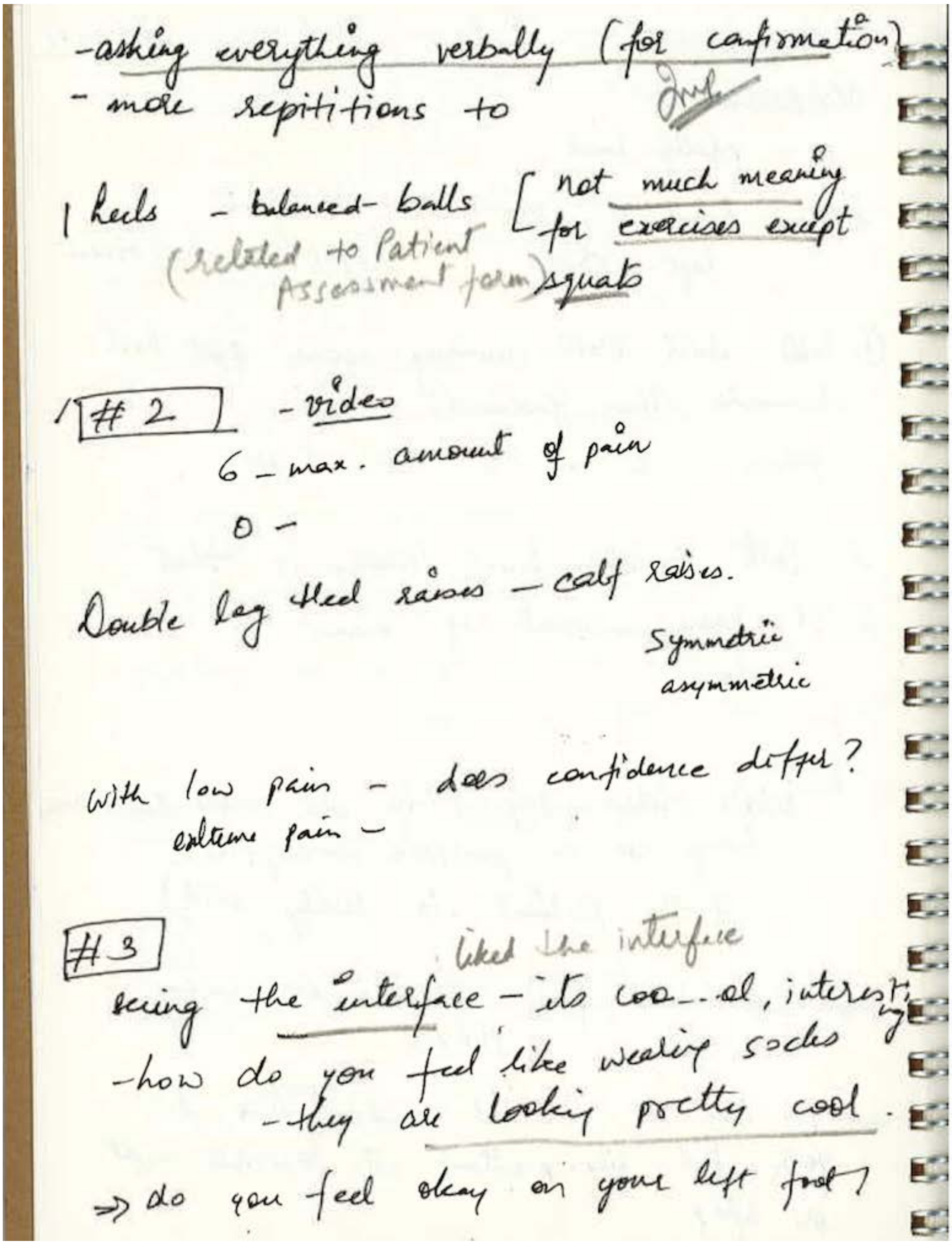
1. How is the session supplemented with information related to the given health issue?
2. When do participants use cues/gestures?
3. What medical information is communicated verbally e.g., strength of limb, pain, mobility issues etc.?

Understanding the limitations of designed technology

1. What technical issues are faced by participants during the session?
2. When does the technology break?
3. What do participants do during technical breakdown (like waiting, anticipating, interpreting the reason or consequences)?
4. What sorts of interactions/activities are limited by the current setup?

C.7. Excerpts from the Notes Diary

This document presents snapshots from my notes diary to illustrate how the notes were taken during the session. This document was referred to in Section 6.3.4 in this thesis. The following notes were taken in session 3 when the participant was present with the following order of the sessions: video consultation *without SoPhy*, video consultation *without SoPhy*, video consultation *with SoPhy*, and video consultation *with SoPhy*.



- asking everything verbally (for confirmation)
- more repititions to

| heels - balanced - balls [not much meaning for exercises except squats
(related to Patient Assessment form)

#2 - video
6 - max. amount of pain
0 -

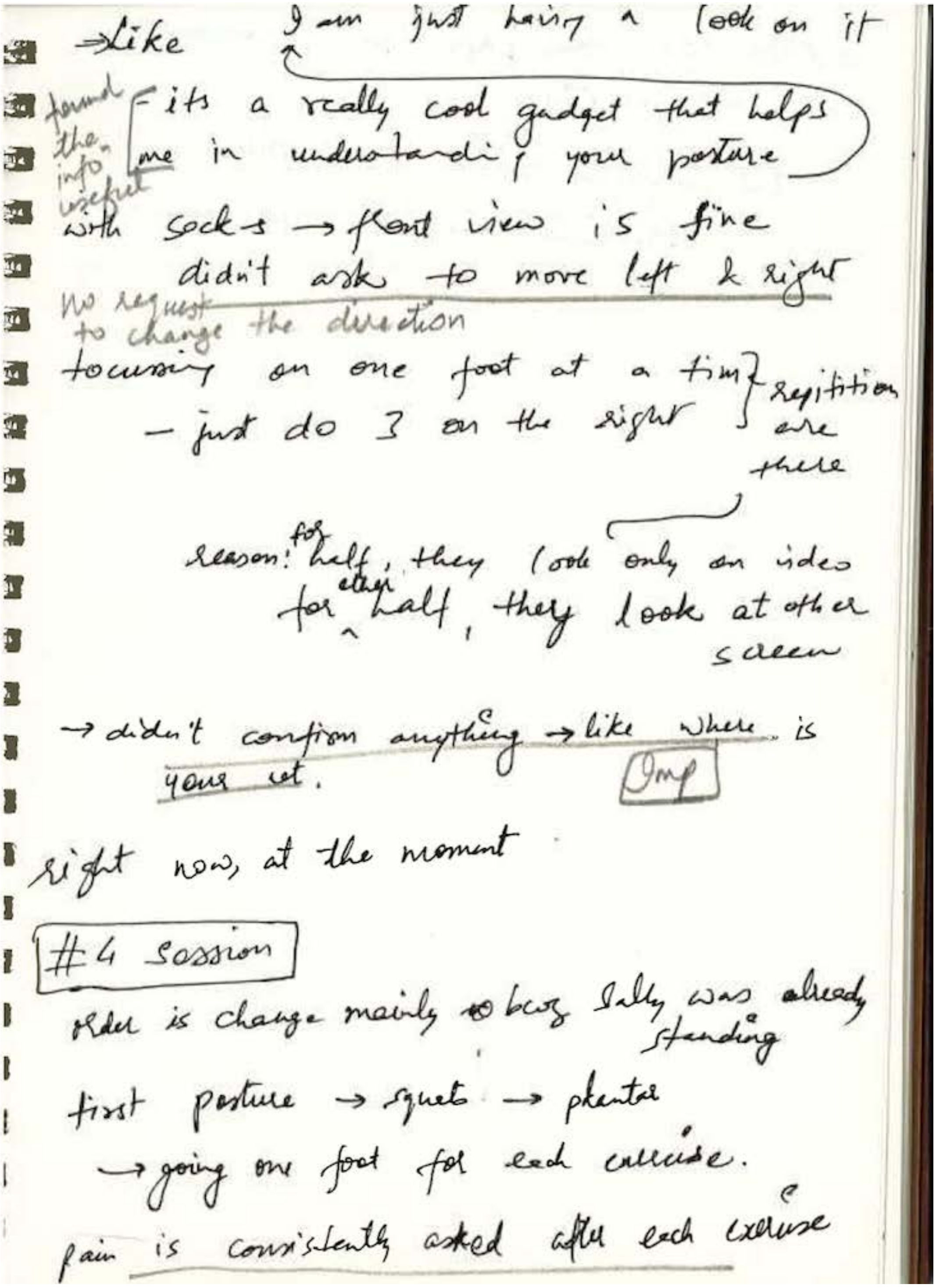
Double leg Heel raises - calf raises.
Symmetric
asymmetric

With low pain - does confidence differ?
extreme pain -

#3 liked the interface
seeing the interface - its coo...ol, interesting
- how do you feel like wearing socks
- they are looking pretty cool.
→ do you feel okay on your left foot?

Figure: Observation notes capturing the comments made by the participants during the session.

Participant 3 required verbal confirmation on her assessment in the first two sessions when she was not presented with the *SoPhy* visualisation. However, she did not require any verbal confirmation with the *SoPhy* visualisation in session 3 and 4. Also, while she was talking to the actor, she appreciated the information presented on the visualisation.



→ Like I am just having a look on it

found the info useful — its a really cool gadget that helps me in understanding your posture

with socks → front view is fine

didn't ask to move left & right

No request to change the direction

focusing on one foot at a time } repitition are there

— just do 3 on the right

Reason: for half, they look only on video
for other half, they look at other screen

→ didn't confirm anything → like where is your wt. Imp

right now, at the moment

#4 session

Order is change mainly bcoz Sally was already standing

first posture → squat → plantar

→ going one foot for each exercise.

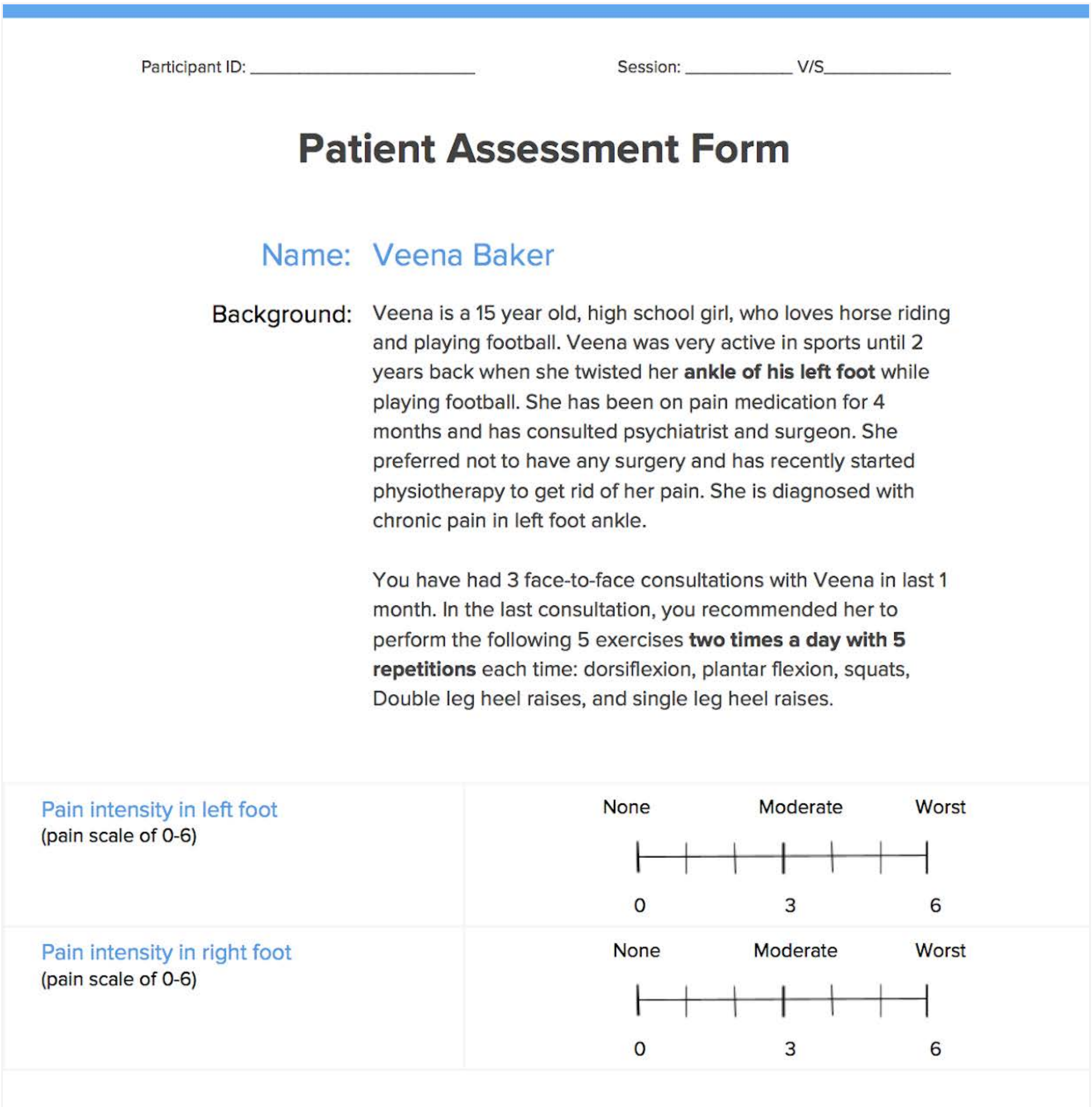
pain is consistently asked after each exercise

Figure: Field notes capturing the arrangement of the participants in the face-to-face session of Laura with Phil.

C.8. Patient Assessment Form

This document provides snapshot of the Patient Assessment Form. The form had eight pages - the first page provides details of the patient, the next six pages are dedicated to the assessment of each exercise, and the last page inquires the overall confidence in assessment. This document was referred to in Section 6.3.4 in this thesis.of the thesis.

The following image presents the first page of the form for the patient profile, Veena Baker. This page briefly described the background and medical history of the patient.



Participant ID: ________________________ Session: ___________ V/S______________

Patient Assessment Form

Name: Veena Baker

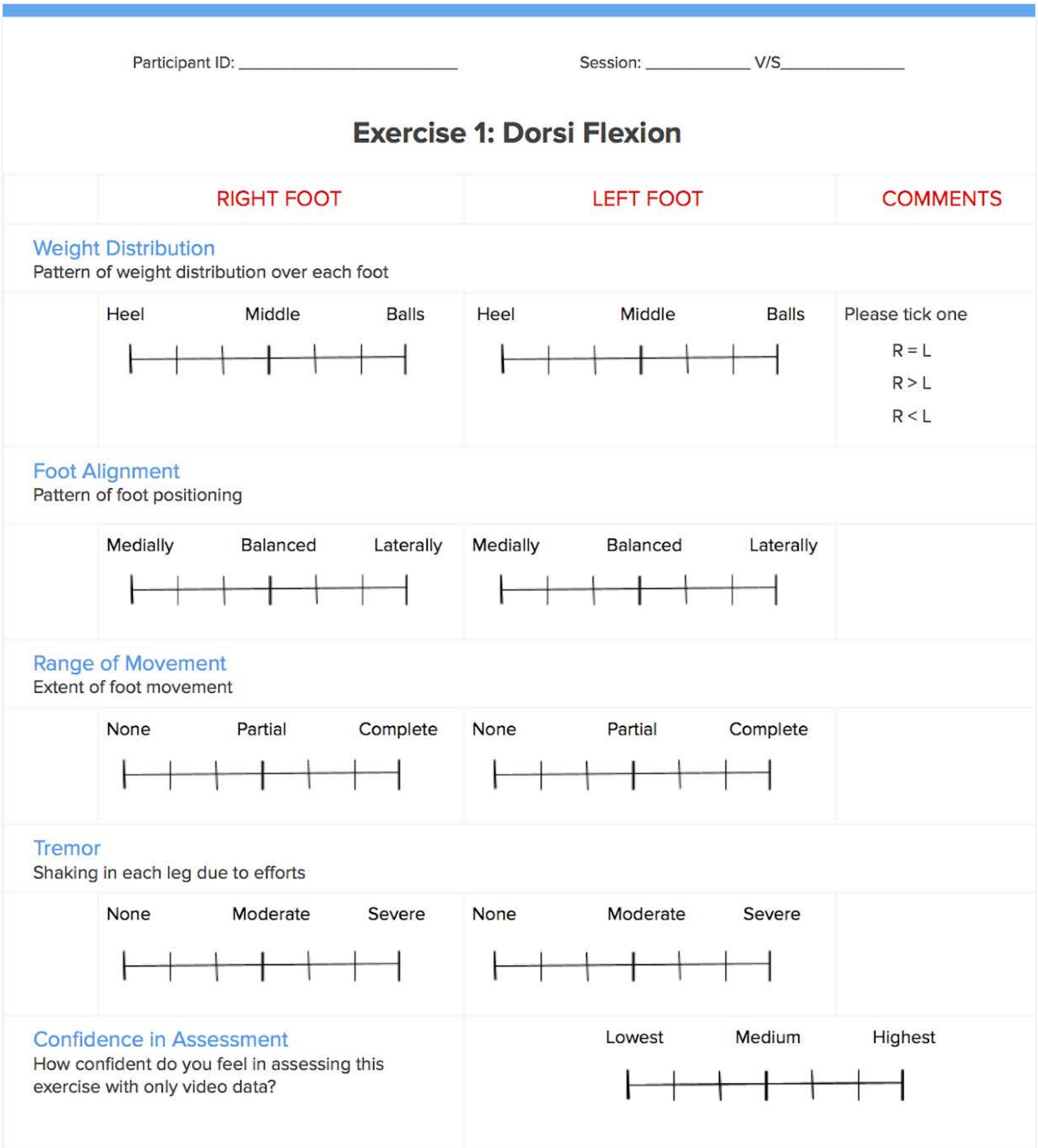
Background: Veena is a 15 year old, high school girl, who loves horse riding and playing football. Veena was very active in sports until 2 years back when she twisted her **ankle of his left foot** while playing football. She has been on pain medication for 4 months and has consulted psychiatrist and surgeon. She preferred not to have any surgery and has recently started physiotherapy to get rid of her pain. She is diagnosed with chronic pain in left foot ankle.

You have had 3 face-to-face consultations with Veena in last 1 month. In the last consultation, you recommended her to perform the following 5 exercises **two times a day with 5 repetitions** each time: dorsiflexion, plantar flexion, squats, Double leg heel raises, and single leg heel raises.

Pain intensity in left foot (pain scale of 0-6)	None Moderate Worst 0 3 6
Pain intensity in right foot (pain scale of 0-6)	None Moderate Worst 0 3 6

Figure : Snapshot of the first page of the form.

The next six pages were dedicated for the assessment of the following six exercises - dorsiflexion, plantar flexion, double leg squats, single leg heel raises, double leg heel raises and walking. Each page presented the same parameters around which the participants were required to assess the patient's movements, namely, weight distribution, foot alignment, range of movement and tremor. Participants also rated their confidence in assessing each exercise. Participants filled in their assessment for each exercise one-by-one. Below I present the snapshot of the form for only one exercise. The form had the same information for the remaining five exercises.



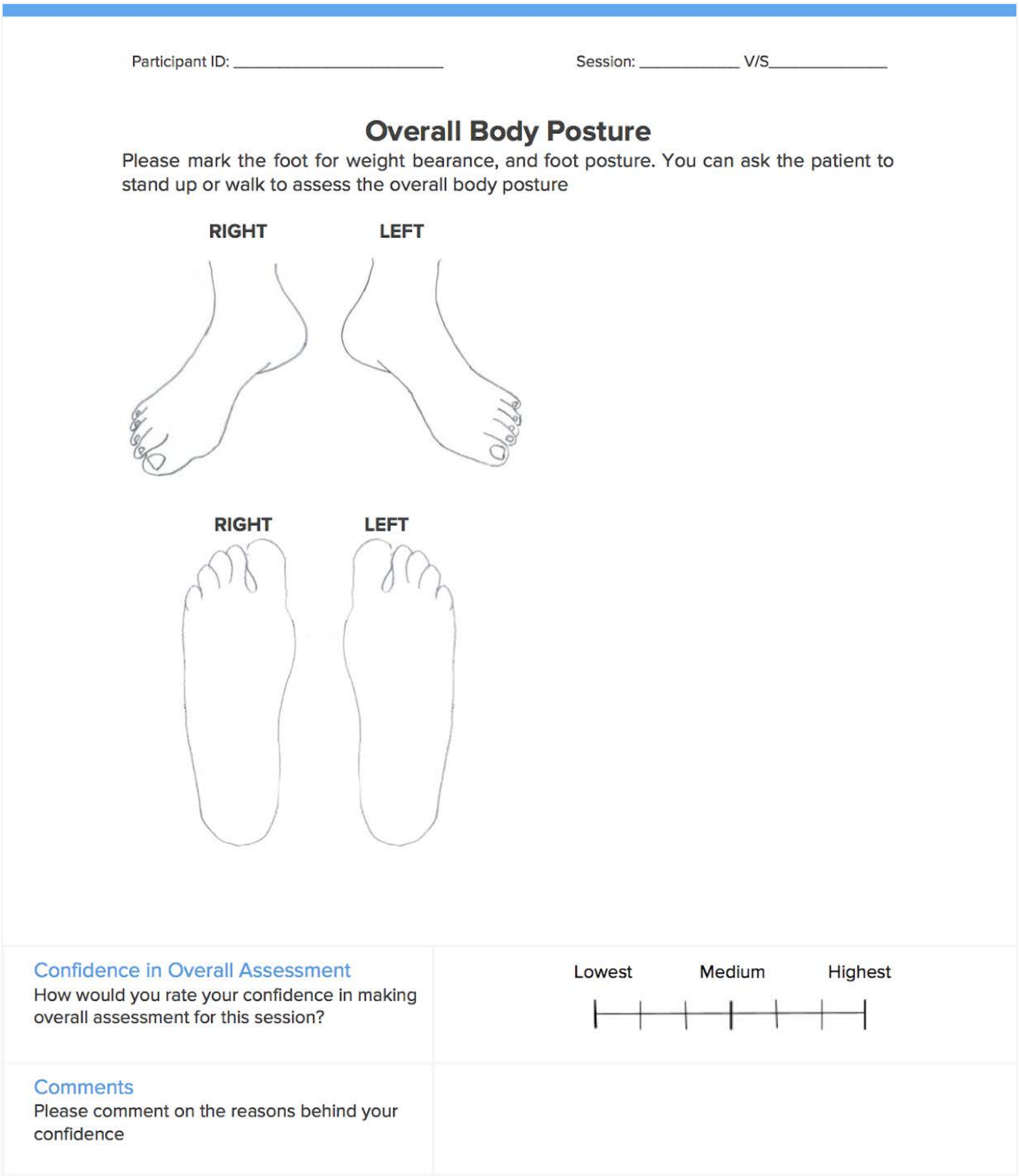
Participant ID: ________________________ Session: ___________ V/S_____________

Exercise 1: Dorsi Flexion

	RIGHT FOOT	LEFT FOOT	COMMENTS
Weight Distribution Pattern of weight distribution over each foot	Heel — Middle — Balls	Heel — Middle — Balls	Please tick one R = L R > L R < L
Foot Alignment Pattern of foot positioning	Medially — Balanced — Laterally	Medially — Balanced — Laterally	
Range of Movement Extent of foot movement	None — Partial — Complete	None — Partial — Complete	
Tremor Shaking in each leg due to efforts	None — Moderate — Severe	None — Moderate — Severe	
Confidence in Assessment How confident do you feel in assessing this exercise with only video data?	Lowest — Medium — Highest		

Figure : Snapshot of the second page of the form.

The last page of the form asked the participant to fill in their overall assessment of the patient's foot. They were also required to rate their overall confidence in assessing the patient and the reasoning behind this confidence.



Participant ID: ______________________ Session: __________ V/S____________

Overall Body Posture

Please mark the foot for weight bearance, and foot posture. You can ask the patient to stand up or walk to assess the overall body posture

RIGHT LEFT

RIGHT LEFT

Confidence in Overall Assessment How would you rate your confidence in making overall assessment for this session?	Lowest Medium Highest
Comments Please comment on the reasons behind your confidence	

Figure : Snapshot of the last page of the form.

C.9. Interview Guide

The following document lists the interview guide that I used to conduct interviews with the participants. This guide was a part of the ethics application approved by the Ethics Advisory Group at the University of Melbourne. In this document, I present the guide that I develop in the beginning of the study to interview study participants. I refined this guide throughout the study as my understanding of the research problem and the context developed over time. This is a comprehensive list of questions that I used flexibly to inquire participants about their experience with *SoPhy*. This document was referred to in Section 6.3.4 in this thesis.

Before sessions

1. Do you currently practise physiotherapy at a hospital?
2. Could you please describe me your experience with physiotherapy sessions?
3. Have you had any experience with video based consultations? How many consultations have you organised thus far?

In between the sessions (break)

1. How did you find the previous session?
2. What challenge did you face in the session?
3. How was this different from previous sessions? (if it was not the first session)
4. How would you rate your confidence for this session?
    a. What is the reason behind it?

After the study sessions

Walkthrough of the four sessions

1. How did you find video consultations in general?
2. What challenges did you face in understanding the patient's movements?
3. Can you compare video consultations with face-to-face consultations?
4. What were the differences across all 4 sessions that you organised today?
5. What differences did you find in sessions with and without socks?
6. How did your confidence change across sessions for
    a. Extreme pain vs. low pain
    b. Socks vs. without socks
    c. Different exercises

Understanding each attribute

1. How important is it to assess weight distribution?
2. How is the information about foot orientation useful?
3. What is the importance of range of movement?

4. Do these three aspects follow any priority order, like one is more important than other?
5. What other information is essential to get a good understanding of the patient's recovery? (tremor, strength, time, speed)
6. How do these three information play differently in f2f setting?

Clarity of visualisations

1. How did you find the information presented through visualisations?
2. What are the benefits of visualisation for patients? (e.g., training, correcting body posture)
3. What did you like about the visualisation?
    a. Display
    b. Amount of information (pictures, numerical data)
    c. Colours
4. What issues did you find with the visualisation?
    a. How can we improve the visualisation? What other information should be added?

Use cases of socks

1. What are the use cases of socks? For what clinical conditions it could be used?
    a. Extreme pain
    b. Medium pain
    c. Low pain
    d. Clinical conditions: rehabilitation, chronic pain, arthritis
    e. Application areas: lower body pain, back pain
2. Are socks more useful for certain exercises or condition than others?
3. What could be the issues with socks?

Managing the information

1. How did you find managing two screens?
2. Did it add any distraction?
3. How would you like to arrange the information presented on the interface?

Socks wearability

1. Show the socks
    a. Questionnaire
    b. How to further improve the socks

C.10. Sock Wearability Questionnaire

Below I present the wearability questionnaire that was used in the study to evaluate the comfort of the *SoPhy* socks. Participants filled this questionnaire after trying out the socks. This document was referred to in Section 6.3.4 in this thesis.

Questionnaire on Sock Wearability

Project title: SmartSox: A Lab based Evaluation of Wearable Technology for Video Consultations

Investigators: Deepti Aggarwal, Bernd Ploderer, Thuong Hoang, Frank Vetere, Mark Bradford

---

Participant ID: ___________

Age: _________

Technology experience:

Do you own and/or have used the following types of devices? If yes, please indicate how frequently you use the device, from 1 (rarely) to 10 (very frequently)

Wii board	Y/N	Frequency ___
Shoe sole with pressure sensors	Y/N	Frequency ___

For the following statements, please rate from 1 to 10 of how much you agree with the statement with regards to your experience with the socks, and provide comments if necessary:

1. Emotion: I feel self-conscious having people see me wear this socks

Strongly disagree									Strongly agree
1	2	3	4	5	6	7	8	9	10

Please explain ____

____

____

2. Attachment: I can feel the socks moving on my body

Strongly disagree									Strongly agree
1	2	3	4	5	6	7	8	9	10

Please explain ____

____

____

3. Harm: I feel some pain or discomfort wearing the socks

Strongly disagree									Strongly agree
1	2	3	4	5	6	7	8	9	10

Please explain ____

____

____

4. Perceived change: Wearing the socks makes me feel physically different. I feel strange wearing it

Strongly disagree									Strongly agree
1	2	3	4	5	6	7	8	9	10

Please explain ____

____

____

5. Movement: I feel that the socks affect the way I move

Strongly disagree									Strongly agree
1	2	3	4	5	6	7	8	9	10

Please explain ____

____

____

6. Anxiety: I do not feel secure wearing the socks

Strongly disagree									Strongly agree
1	2	3	4	5	6	7	8	9	10

Please explain ____

____

____

Thank you for your feedback.

C.11. Different Passes of the Data Analysis

This document describes the coding of the data to generate themes. The document was referred to in Section 6.3.5 in this thesis.

By reading the interview transcripts and observation notes diary repeatedly, I generated the following 19 themes, 16 related to the interactions with *SoPhy* - listed as F1, F2 and so on, and three related to the issues with using *SoPhy* - listed as I1, I2 and I3.

F1: First interactions with *SoPhy* was overwhelming

F2: *SoPhy* acted as a guide for assessment

F3: *SoPhy* offered deep insights regarding weight distribution

F4: *SoPhy* helped in comparing range of movements

F5: *SoPhy* provided information equivalent to multiple camera views

F6: *SoPhy* required fewer repetitions in extreme pain profiles

F7: *SoPhy* helped in comparing the subtle difference in low pain profile

F8: *SoPhy* offered objectivity to assessment

F9: *SoPhy* helped in assessing natural movements

F10: *SoPhy* was appreciated as a mobile gait lab/ for dynamic movements

F11: *SoPhy* offered an extra eye when the patient was out-of-view

F12: *SoPhy* supports different needs of participants / Appreciating the visualisation

F13: *SoPhy* is useful beyond lower limb assessment

F14: *SoPhy* could provide playful encouragement

F15: *SoPhy* could offer live feedback for patients

F16: *SoPhy* has potential in face-to-face consultations

I1: Interpreting two source of information simultaneously was challenging

I2: Value of range of movement did not align with the clinical practise

I3: Size and color of socks interfered in the assessment

After generating these themes, I read the interview transcripts again and coded the participant quotations with the relevant theme numbers. The below snapshot is from the interview transcript of participant 5. While I coded the transcript with the theme number, I also added comments from the observation notes.

Challenges of video consultation

If it was a full therapy session, then the challenges include the hands-on experience and teaching them exercises. But I think for follow-ups, it could be quite useful. I did not feel entirely different to observe bodily movements over video. There are some positives of video as well like you can take a second and think whereas in person you feel less comfortable to take that time. You are more inclined to give an answer or talk straight away in f2f.

Socks data vs. without socks sessions It not only helped in confirmation but sometimes also added info that were not directly visible.

F2 (The socks data helped me to confirm my hypothesis. There was particularly one time when it really helped me. I did not quite get the lateral position of her [patient's] foot, but the numbers on the system guided me.)

F2 (Initially I found it very confusing of what to see and when. But with a bit of practise, I felt I was able to use both. It was mainly because I hadn't done this before. I was getting my head around on what I was getting with the data, while also trying to look at their movement.)

F2 (I think the system could be a useful adjunct to looking at what's going on.)

Extreme pain vs. low pain

F6 (I think it's more useful in the minor pain where the movements are lot more subtle.) In the two sessions when the patient was in lot more pain, you could see their movements quite clearly.

F12 F15 F16 (Training the patients will happen with everyone across all pain severity. A good treatment helps the patient to get their movements normalized. Training is particularly more helpful for patients in **severe pain** as they tend to avoid movements. The more they avoid their movements, the longer it is going to take to achieve normal movements.) H

Start with this, that training is crucial in severe pain. So, I would want to use the system in first setting.

Uses for patients

F14/F15 **For severe pain**, the system might be more useful for them [patients] to see what's happening, so they could see that they are scoring 3 on that affected area whereas it's 18 on the other foot for the same location. And then you could describe how they need to optimize their movements to get even numbers.

After this pass, I developed a document containing all the themes and the corresponding participant quotations. I reread this document to review the themes in order to merge multiple themes together or separate the themes. I continued with the coding and reviewing iteratively on the printed copy to finally define five themes that are described in the chapter. The below snapshots show the iteration on the themes and participant quotations.

F11: SoPhy offered an extra eye when the patient was out-of-view

"What makes this tool special is that even if the quality of video is low, I will still get the details. I think having this information is very helpful especially when you can't see the patient in person. Like when I asked her to walk and she went away from camera, but I can still see how she is walking here [on web-interface]." (P3)

F12: SoPhy supports different needs of participants / Appreciating the visualisations

"The picture tells me the position of foot, whether it is plantarflexed or dorsiflexed. I liked the picture and the number both. I am more of a visual person. Also, the weight bearance is quite easy for me to understand, so I would like the program to guide me with the range and orientation- lateral and medial moves as they are more difficult to me to observe." (P7)

"The number and color for weight distribution, both are good. And I like this view of the foot from underneath. The circles give me an indication of where the weight is, it is not ambiguous in the way that there are only three sensors and the visualisation shows me complete sole." (P5)

F13: SoPhy is useful beyond lower limb assessment

"Probably 100% of lower limb issues will get benefitted from this technology. Even the upper limb issues will have benefits as a lot of upper limb things are again connected with lower limb balance like any issue with the hips will change the biomechanics down there." (P10) Another participant mentioned, "I can see the system having a big role for lower limb rehabilitation. But it would be useful for someone who has spinal issues, and therefore can't maintain a proper body posture. It also has benefits for anyone who have had falls and struggling with weight bearing movements." (P9) "[..] Sports athlete would be another area where people suffer with chronic pain, and there the system can be useful. Even for an upper limb problem, since everything is connected to foot, the system might have different roles." (P8) "The system is useful for optimizing the running mechanics of athlete and in the rehabilitation of stroke patients." (P5)

F14: SoPhy could provide playful encouragement

of what is the normal biomechanics of an average person. But that is also challenging - no one is the same, there are age differences, and there are sex differences." (P10)

"Generally, we learn about the weight distribution from the noise they are making while walking like if they have been hitting the ground softly or hardly. But of course, it has other caveats like how much the person weigh or what the person is wearing. Getting these numbers are more valuable than just eyeballing." (P5)

"This system provides more objective data. So far our domain has been very subjective, so how you measure movements of a patient, is very different from how someone will do. Then there comes the issue of transferring a patient from one clinician to other. I think having the objective measure will help us in great deal." (P1)

F9: SoPhy helped in assessing natural movements

"We use Goniometer to check the range of movements. So we ask the patient to go the maximum they can for their joint. But we don't know whether it is their maximum range or not. It could be that because of fear, they are not going far enough. I think the system has merits in capturing the dynamic movements in a natural setting." (P9??) "Being able to do actual walking not just marching on the spot is a major benefit with the socks as you could recreate the normal walking with the socks. The socks have more potential to modify the environment like you can take stairs, slope or shoes. And then you can reproduce the natural biomechanics in different environments with socks." (P10)

F10: SoPhy was appreciated as a mobile gait lab /dynamic movements

SoPhy was appreciated to support both static and dynamic movements with real-time access to the captured data. One participant compared the system with the traditional gait lab: "Normally we do gait analysis in the dedicated lab. It is a bit complex setup that requires arrangement in terms of booking the lab, understanding the system, and it's not always accessible. The socks system is a great example of mobile gait lab. I can see their biomechanics related to walking, and exercising in real-time." (P6) Similarly, another participant highlighted the ease to perform gait analysis with *SoPhy:* "This is such an easy tool to do general gait analysis where you can see how the weight is transferring with exercises like walking in real-time." (P9)

C.12. Snippets of the Quantitative Analysis

This document presents snapshots of the tools with which quantitative analysis was conducted on the data. This document was referred to in Section 6.3.5 in this thesis.

Data collected from the video recordings and the Patient Assessment form were analysed using the Aligned Rank Transform tool in R. Below I provide a snapshot of the analysis.

RGui (64-bit) - [R Console]

File Edit View Misc Packages Windows Help

```
Warning message:
package 'ARTools' is not available (for R version 3.4.3)
> ex1
    Participant Condition Pain Wt_R Wt_L Wt_O Align_R Align_L ROM_R ROM_L
6             1         1    1  1.0  3.0    2       4     3.0   4.0   2.0
12            2         1    1  4.0  4.0    1       4     4.0   7.0   3.0
18            3         1    1  3.0  2.0    2       4     3.0   5.0   3.0
24            4         1    1  1.5  2.5    2       3     3.5   6.5   3.5
30            5         1    1  1.0  2.5    1       4     5.0   6.0   2.0
36            6         1    1  1.0  2.0    1       4     2.0   7.0   4.0
42            7         1    1  1.0  2.5    2       4     4.0   7.0   2.0
48            8         1    1  2.0  3.5    1       4     4.0   5.5   3.0
54            9         1    1  1.0  1.0    2       2     4.0   7.0   2.5
60           10         1    1  1.0  3.0    2       5     4.0   7.0   2.0
66            1         1    2  2.0  1.0    3       6     4.0   3.0   4.0
72            2         1    2  4.0  4.0    3       5     4.0   6.5   7.0
78            3         1    2  2.0  4.0    3       5     4.0   5.0   4.0
84            4         1    2  7.0  1.0    3       4     4.0   5.5   7.0
90            5         1    2  1.0  1.0    1       4     4.0   5.0   7.0
96            6         1    2  1.0  1.0    1       4     4.0   7.0   7.0
102           7         1    2  3.0  1.0    1       5     4.0   4.0   7.0
108           8         1    2  3.0  1.5    3       4     4.0   6.0   7.0
114           9         1    2  1.0  1.0    3       5     4.0   5.5   7.0
120          10         1    2  1.0  1.0    1       5     4.0   6.0   7.0
126           1         2    1  1.0  6.0    2       4     6.0   4.0   2.0
132           2         2    1  4.0  4.0    1       4     4.0   7.0   3.5
138           3         2    1  5.0  2.0    2       5     2.0   5.0   3.0
144           4         2    1  1.0  2.5    2       4     4.0   6.5   2.5
150           5         2    1  1.0  2.0    2       4     5.0   6.0   3.0
156           6         2    1  2.0  2.0    2       4     4.0   7.0   2.0
162           7         2    1  1.0  1.5    2       4     4.0   7.0   4.0
```

Figure : Snapshot of the R Console showing the analysis on the Patient Assessment Form data.

The following image shows how the wearability questionnaire data was populated in the Microsoft Excel sheet. The collected data was analysed using Microsoft Excel with the Analysis ToolPak add-in.

Participants Name	1. Emotions	2. Attachment	3. Harm	4. Perceived Change	5. Movement	6. Anxiety
1	1	1	1	1	1	1
2	1	2	1	1	1	4
3	2	1	1	1	2	3
4	2	1	1	2	1	1
5	3	2	2	2	2	2
6	1	2	1	2	2	1
7	1	1	1	3	2	1
8	1	1	1	1	1	1
9	1	2	1	4	4	1
10	1	1	1	1	1	1

1. Emotions		*2. Attachment*		*3. Harm*	
Mean	**1.4**	**Mean**	**1.4**	**Mean**	**1.1**
Standard Error	0.221108319	Standard Error	0.163299316	Standard Error	0.1
Median	1	Median	1	Median	1
Mode	1	Mode	1	Mode	1
Standard Deviation	**0.699205899**	**Standard Deviation**	**0.516397779**	**Standard Deviation**	**0.316227766**
Sample Variance	0.488888889	Sample Variance	0.266666667	Sample Variance	0.1
Kurtosis	2.045454545	Kurtosis	-2.276785714	Kurtosis	10
Skewness	1.657724729	Skewness	0.484122918	Skewness	3.16227766
Range	2	Range	1	Range	1
Minimum	1	Minimum	1	Minimum	1
Maximum	3	Maximum	2	Maximum	2
Sum	14	Sum	14	Sum	11
Count	10	Count	10	Count	10
Confidence Level(95.0%)	0.500181768	Confidence Level(95.0%	0.369408718	Confidence Level(95.(	0.226215716

4. Perceived Change		*5. Movement*		*6. Anxiety*	
Mean	**1.8**	**Mean**	**1.7**	**Mean**	**1.6**
Standard Error	0.326598632	Standard Error	0.3	Standard Error	0.339934634
Median	1.5	Median	1.5	Median	1
Mode	1	Mode	1	Mode	1
Standard Deviation	**1.032795559**	**Standard Deviation**	**0.948683298**	**Standard Deviation**	**1.0749677**
Sample Variance	1.066666667	Sample Variance	0.9	Sample Variance	1.155555556
Kurtosis	0.945870536	Kurtosis	3.533215755	Kurtosis	1.863905325
Skewness	1.240564978	Skewness	1.717780457	Skewness	1.69056958

Figure : Snapshot of the excel sheet showing descriptive analysis on the Sock Wearability Questionnaire.

Appendix D
Material for Study 3

Overview: This Appendix provides additional documents about the data collection and analysis process used in Study 3. These documents are provided to make the research process transparent and auditable. The listed documents were referred to in Chapter 7 of this thesis. The Appendix contains the following documents:

D.1 presents the plain language description of the project provided to participants

D.2 presents the script provided to clinician for recruitment of patients

D.3 lists the observation guide that was used to collect data in the field

D.4 presents excerpts from the observation notes diary

D.5 lists the interview guide that was used to interview participants

D.6 presents details on the earlier iterations of the data analysis

D.7 presents coding process of the transcribed interviews

D.1. Plain Language Description for Participants

The following document provides the plain language description of the project that was provided to participants in the study. As participants for Study 3 were clinicians, patients and their carers, I developed three plain language statements of the project. These documents were part of the ethics application approved by the Ethics Advisory Group at the Royal Children's Hospital. The hospital ethics guidelines refer plain language description of the project as information letter. This document was referred to in Section 7.2 in this thesis.

THE UNIVERSITY OF MELBOURNE

The Royal Children's Hospital Melbourne

INFORMATION LETTER

HREC Project Number: 36312A

Research Project Title: Evaluation of a Wearable Technology during Video Consultations of Physiotherapy

Principal Investigator: Mark Bradford, Senior Physiotherapist, Department of Anaesthesia and Pain Management, Royal Children's Hospital

Dear Clinician,

What is the research project about?

The purpose of this research is to trial a new technology called *SoPhy*, which is designed to help physiotherapists monitor lower limb exercises during a video consultation. *SoPhy* consists of different sensors embedded on the sole and around the ankle of a sock. These sensors capture weight distribution and foot orientation when worn during exercise. This information is presented on a web-interface in

real-time to provide physiotherapists with detailed insights into a patient's movements during video consultations.

Your participation in this study will help us to evaluate the overall usefulness of *SoPhy* in video consultations for physiotherapy.

This project will form a part of a PhD research project for Deepti Aggarwal, a student researcher from the University of Melbourne.

Who is funding this research project?

Funding for this project will come through the student researcher's PhD scholarship from the University of Melbourne.

The University of Melbourne may directly or indirectly benefit financially from knowledge acquired through analysis of the data provided by your involvement in the project.

You will not benefit financially from your involvement in this research project even if, for example, the knowledge acquired from analysis of the data provided by your involvement proves to be of commercial value to *The University of Melbourne*.

In addition, if knowledge acquired through this research leads to discoveries that are of commercial value to *The University of Melbourne*, the study doctors or their institutions, there will be no financial benefit to you, or family from these discoveries.

Why am I being asked to be in this research project?
We would like to invite you to participate in the study as you provide lower limb treatment at the Royal Children's Hospital.

What does participation in this research involve?
We would like you to:
(1) Trial *SoPhy* in your physiotherapy consultations
(2) Take part in an interview to give feedback on *SoPhy*

Your participation includes trialing *SoPhy* with up to 4 patients. For each patient, the trial will include organizing at least two consultations with *SoPhy* – the first will be a face-to-face consultation and the other will be a simulated video consultation. Observations will happen at the hospital in your consultation room. You will be asked to use the information presented on the *SoPhy* web-interface during the consultation. The student researcher will take notes on the communication and interactions that happen between you and your patient, as supported by *SoPhy*. While taking notes, we will not include specific health information about the patient. Instead, notes about medical information will only be taken in general terms to understand how such information is communicated through *SoPhy* and other forms (e.g., paper based forms) during the course of the consultation. With your permission, we would also take photographs of the setup (without any people) before or after the consultation to record the arrangement of technology in the consultation.

After each consultation, we would also like to interview you to get feedback about your overall experience with *SoPhy*. This interview will be at a time and place convenient for you, or via telephone. The interview will last for approximately 20-30 minutes. With your permission, we would like to make an audio recording of our conversations, to later analyse our discussion in detail.

Finally, we also seek your support to assist us in identifying potential patients for this study whose consultations would be appropriate for observations by the student researcher.

What are my alternatives to taking part?
Your participation in this study is voluntary. If you do not wish to take part, or choose to withdraw from the project, it will not affect your employment at The Royal Children's Hospital.

You are free to withdraw from the project at any time without giving us a reason. If you withdraw, we would like to use any information that we have already collected about you after seeking your permission. In such scenarios, data collected about your patients will be considered for the study purposes, unless requested otherwise by the patient.

What are the potential benefits for me and other people in the future?
You will have an opportunity to try out a novel sensor-based technology, designed to help clinicians and patients communicate more effectively during video consultations. Some participants may also appreciate an opportunity to experience video consultation, which might be helpful for them in future. This research will assist us in understanding the design of future systems for video consultations.

What are the possible risks, side effects, discomforts, and/or inconveniences?
We don't expect that this study introduces any risks to you or your patient. However, we do understand that having a researcher sitting in the consultation or discussing medical information in front of the researcher could make you or your patient feel uncomfortable. Please feel free to ask the researcher to leave the room at any time, if you wish to discuss any private information with your patient.

We understand that participating in the follow-up interview after the consultation would require time from your busy schedule. To minimize your time commitment, we will keep the interview short and focused to our research aims. Also, we have done our best to make sure that the interview questions do not cause you any distress. However, you do not have to answer any question that you may find uncomfortable.

If we ask questions regarding your interaction with the technology, our aim is to evaluate the strengths and weaknesses of the technology and not to judge your technical knowledge. If the researcher observes or discusses the session's medical information, we want to assure you that we will not record specifics of this information.

What will be done to make sure my information is confidential?
All the information collected will be stored securely in the Department of Computing and Information Systems at the University of Melbourne for 7 years after the youngest participant turns 18 years of age. After this time, we will destroy it. All the electronic files will be password protected and kept on computers in the secured offices to which only members of the research team and the RCH ethics committee will have access. In accordance with relevant Australian and/or Victorian privacy and other relevant laws, you have the right to access and correct the information we collect and store about your patient. Please contact us if you would like to access this information.

We will record your personal information to present the study findings on how *SoPhy* was used by patients and clinicians during consultations. Personal information apart from your age, gender and years of experience will not be revealed. The stored information will be re-identifiable. This means that we will remove identifying information such as your name and give the information a special code. Only the research team can match the name to the respective code, if it is necessary to do so. Also, in cases where we need to refer you in any publications published out of this work, we will use a pseudonym.

Will I be informed of the results when the research project is finished?
At the end of the project, we will send you a summary of the project's results. Please be mindful that the findings will be an indicative of the whole group of the participants and not of every individual. Also, results from the study will be presented at conferences or published in journals on health and technology.

From where can I get further Information?
Should you require any further information, or have any concerns, please do not hesitate to contact any of the following people:

- Deepti Aggarwal (daggarwal@student.unimelb.edu.au, 0 47007 3052)
- Dr. Mark Bradford (mark.bradford@rch.org.au, 03 9345 6434)

How do I agree to participate?
If you would like participate, please read and sign the attached Consent Form. Please return the signed Consent Form to Deepti Aggarwal as hard copy or via email to daggarwal@student.unimelb.edu.au. Please keep a copy of the Information Letter and Consent Form for your reference.

Thank you for your help.

If you have any concerns about the project or the way it is being conducted, and would like to speak to someone independent of the project, please contact: Director, Research Ethics & Governance, The Royal Children's Hospital Melbourne on telephone: (03) 9345 5044.

The following document provides the plain language description of the project that was provided to patients in Study 3. Similar information letter was provided to the patient's carers to seek their permission for their kids to participate in the study. Parent's consent was compulsory as the study was conducted with kids under 18 years of age.

THE UNIVERSITY OF MELBOURNE

The Royal Children's Hospital Melbourne

INFORMATION LETTER

HREC Project Number: 36312A

Research Project Title: Evaluation of a Wearable Technology during Video Consultations of Physiotherapy

Principal Investigator: Mark Bradford, Senior Physiotherapist, Department of Anaesthesia and Pain Management, Royal Children's Hospital

Dear Participant,

What is the research project about?

The purpose of this research is to trial a new technology called *SoPhy*, which is designed to help physiotherapists monitor lower limb exercises during a video consultation. *SoPhy* consists of different sensors embedded on the sole and around the ankle of a sock. These sensors capture weight distribution and foot orientation when worn during exercise. This information is presented on a web-interface in real-time to provide physiotherapists with detailed insights into a patient's movements during video consultations.

Your participation in this study will help us to evaluate the overall usefulness of *SoPhy* in video consultations for physiotherapy.

This project will form a part of a PhD research project for Deepti Aggarwal, a student researcher from the University of Melbourne.

Who is funding this research project?
Funding for this project will come through the student researcher's PhD scholarship from the University of Melbourne.

The University of Melbourne may directly or indirectly benefit financially from knowledge acquired through analysis of the data provided by your involvement in the project.

You will not benefit financially from your involvement in this research project even if, for example, the knowledge acquired from analysis of the data provided by your involvement proves to be of commercial value to *The University of Melbourne*.

In addition, if knowledge acquired through this research leads to discoveries that are of commercial value to *The University of Melbourne*, the study doctors or their institutions, there will be no financial benefit to you, or family from these discoveries.

Why am I being asked to be in this research project?

We would like to invite you to participate in the study as you are seeking lower limb physiotherapy treatment at the Royal Children's Hospital (RCH).

What does participation in this research involve?
We would like to:
(1) Trial *SoPhy* in your physiotherapy consultation
(2) Take part in an interview to give feedback on *SoPhy*

The trial will include participation in at least two consultations with your physiotherapist – the first will be a face-to-face consultation and the other will be video consultation. All consultations will happen at the hospital. You will be asked to wear the *SoPhy* sensor socks and continue with your scheduled consultation. You can wear these sensor socks with your socks underneath. During the session, a researcher will sit with you. The researcher will take notes on the communication and interactions that happen between you and your physiotherapist, as supported by *SoPhy*. While taking notes, we will not record your specific health information. Instead, notes about medical information will only be taken in general terms to understand how such information is communicated through *SoPhy* and other forms (e.g., paper based forms) during the course of the consultation.

After each consultation, we would also like to interview you to get feedback about your overall experience with *SoPhy*. We will questions such as: How *SoPhy* helped you in communicating the movement related information? How did the information presented on the web-interface help you? During the interview, you will also be asked to fill in a short questionnaire on the wearability of the *SoPhy* socks - which will only take a couple of minutes to finish.

This interview will be at a time and place convenient for you, or via telephone or video chat. The interview will last for approximately 20-30 minutes. With your permission, we would like to make an audio recording of our conversations, to later analyse our discussion in detail.

What are my alternatives to taking part?
Your participation in this study is voluntary. If you do not wish to take part, or choose to withdraw from the project, it will not affect your access to the best available treatment options, care and educational support from The Royal Children's Hospital.

You are free to withdraw from the project at any time without giving us a reason. If you withdraw, we would like to use any information that we have already collected about you, after seeking your permission.

What are the potential benefits for me and other people in the future?
You will have an opportunity to try out a new technology, designed to help clinicians and patients communicate more effectively during video consultations. Some participants may also appreciate an opportunity to experience video consultation, which might be helpful for them in future. This research will assist us in understanding the design of future systems for video consultations.

What are the possible risks, side effects, discomforts, and/or inconveniences?
We don't expect that this study introduces any risks to you. However, we do understand that having a researcher sitting in the consultation or discussing medical information in front of the researcher could make you feel uncomfortable. Please feel free to ask the researcher to leave the room at any time, if you wish to discuss any private information with the clinician.

We understand that interviewing you after the consultation requires extra time commitment from your end. To minimize your time commitment, we will keep the interview short and focused to our research aims. Also, we have done our best to make sure that the interview questions do not cause you any distress. However, you do not have to answer any question that you may find uncomfortable.

If we ask questions regarding your interaction with the technology, our aim is to evaluate the strengths and weaknesses of the technology and not to judge your technical knowledge. If the researcher observes or discusses the session's medical information, we want to assure you that we will not record specifics of this information.

What will be done to make sure my information is confidential?
We intend to protect your confidentiality to the fullest extent. In this regard, private information about your health will not become a part of this research. Additionally, any collected information that can identify you will be treated as confidential and used only in this project unless otherwise specified. We can disclose the information only with your permission, except as required by law.

All the information collected will be stored securely in the Department of Computing and Information Systems at the University of Melbourne for 7 years after the youngest participant turns 18 years of age. After this time, we will destroy it. All the electronic files will be password protected and kept on computers in the secured offices to which only members of the research team and the RCH ethics committee will have access.

The stored information will be re-identifiable. This means that we will remove identifying information such as your name and give the information a special code. Only the research team can match the name to the respective code, if it is necessary to do so. Personal information apart from your age and gender will not be revealed. Also, in cases where we need to refer you in any publications published out of this work, we will use a pseudonym.

Will I be informed of the results when the research project is finished?
At the end of the project, we will send you a summary of the project's results. Please be mindful that the findings will be an indicative of the whole group of the participants and

not of every individual. Also, results from the study will be presented at conferences or published in journals on health and technology.

From where can I get further Information?

Should you require any further information, or have any concerns, please do not hesitate to contact any of the following people:

- Deepti Aggarwal (daggarwal@student.unimelb.edu.au, 0 47007 3052)
- Dr. Mark Bradford (mark.bradford@rch.org.au, 03 9345 6434)

How do I agree to participate?

If you would like to participate, please read and sign the attached Consent Form. Please return the signed Consent Form to Deepti Aggarwal as a hard copy or via email to daggarwal@student.unimelb.edu.au. You can also give it to your clinician at the beginning of the consultation. Please keep a copy of the Information Letter and Consent Form for your reference.

Thank you for your help.

If you have any concerns about the project or the way it is being conducted, and would like to speak to someone independent of the project, please contact: Director, Research Ethics & Governance, The Royal Children's Hospital Melbourne on telephone: (03) 9345 5044.

D.2. Clinician's Script

This document presents the script provided to clinicians to help them in describing the project to their clients. This document was a part of the ethics application approved by the Ethics Advisory Group at the Royal Children's Hospital. The document is referred to in Section 7.4.3 of the thesis.

Project Title: Evaluation of a Wearable Technology during Video Consultations of Physiotherapy

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Physiotherapists from the Department of Anaesthesia and Pain Management will help us in identifying potential patients for the study. They will provide the following information to the potential patients and carers to invite them for participation. Clinicians will appropriate the following script as seen necessary:

1. We are looking at trialling a new device that could give us more information about the exercises that you/your child does during the consultation. The device is a pair of socks with sensors that you/your child can wear on top of their socks. When you/your child wear the sensor socks and perform exercises, the socks record the weight bearing patterns and display it on a computer. We can see the information as a feedback on your/your child's movements.

2. The study will happen at RCH. Participation in the study requires an extra time commitment of around 30 minutes. The researchers from the University of Melbourne will join us from the start of the consultation. They will provide us the sensor socks that you/your child will wear during the consultation. And at the end, the researchers will ask you/your child a set of questions regarding the sensor socks.

3. We plan to use the device for our telehealth patients. Therefore, in the study we will meet in two sessions. The first session will be a face-to-face consultation. And for the second one, we will be in different rooms here at the hospital, as if you were telehealth client(s). We will then see and talk to each other over video.

4. Participation in this research is completely voluntary and your decision to participate will not influence your ongoing treatment at RCH.

5. You will be able to find more details in the Information Statement. Here is your copy (patient/carer will receive a copy of the Information Statement and Consent Form). If you have any other questions, you can also email Deepti Aggarwal at daggarwal@student.unimelb.edu.au, or call her on: 0470 073 052.

Following this, the respective clinician will inform the student researcher (Deepti Aggarwal) about the scheduled consultation via email or telephone.

D.3. Observation Guide

The following document presents the observation guide that I used to take notes during the study. This guide was a part of the ethics application approved by the Ethics Advisory Group at the Royal Children's Hospital. This document presents the guide that I developed at the start of the study to conduct observations. I refined this guide throughout the study as my understanding of the research problem and the context developed over time. This document was referred to in Section 7.4.5 in this thesis.

I passively observed clinicians and patients during both video and face-to-face phases of a session to understand the following:

- Understand the setup of a consultation
- Understand the process
- Understand the interactions with the *SoPhy* web-interface
- Understand the wearability of the interactive socks
- Understand the limitations of *SoPhy*

Following are a set of sample questions related to each topic that guide my observations.

Understanding the setup

1. What is the setup of the room? How does the room setup change before, during, and after the consultation?
2. How are the two screens: one for the video call and other for the *SoPhy* web-interface, organized by participants?
3. Who are involved in the session and what are their roles?
4. How do participants arrange themselves around the available technology?
5. How do participants arrange themselves with respect to each other?

Understanding the process

1. What is the purpose of the consultation?
2. How does the consultation progress across different phases (Opening, complaint, examination, diagnosis, treatment and closing)?
3. When do participants use cues/gestures?
4. What medical information is communicated verbally?
5. Who interacts with whom and why?

Understanding the interactions with the SoPhy web-interface

1. When do participants refer to the web-interface?
2. How do participants read the visualizations presented on the web-interface?

3. What conversations are raised around *SoPhy?* And in which phase?
4. How is the information related to weight distribution discussed? Do participants talk about the change in colors or numbers of weight distribution?
5. How is the information related to foot orientation considered? Do participants talk about the numbers or the foot images?
6. When do participants use 'Canvas'? What do they draw on it?
7. How is Canvas used to discuss weight distribution and foot orientation?

Understanding the wearability of the interactive socks

1. How do patients walk or do different exercises when wearing the socks?
2. What sorts of interactions do patients perform with the socks?

Understanding the limitations of SoPhy

1. What technical issues are faced with *SoPhy* during the consultation?
2. When did *SoPhy* break?
3. What did participants do during the technical breakdown (e.g., waiting, anticipating, interpreting the reason or consequences)?
4. What sorts of interactions do *SoPhy* limit?

D.4. Excerpts from the Field Notes Diary

This document presents snapshots from my field notes diary. The document is referred to in Section 7.4.5 of the thesis. During the consultation, I took shorthand notes to capture the interactions of physiotherapists and patients with and around *SoPhy*. Key topic of the conversations were noted as text, whereas sketches were used to record the visualisation that was important for patients or physiotherapists at particular instances.

The below snapshot is taken from session 4, video consultation with Paige. To record the visualisation of the weight distribution, I noted down the circle size and approximate color from the continuous color spectrum. For instance, size 1, 2 and 3 to record the circle size, and an approximate color from the continuous spectrum considering the color band for each range, i.e., 0-10, 10-20 and 20-30.

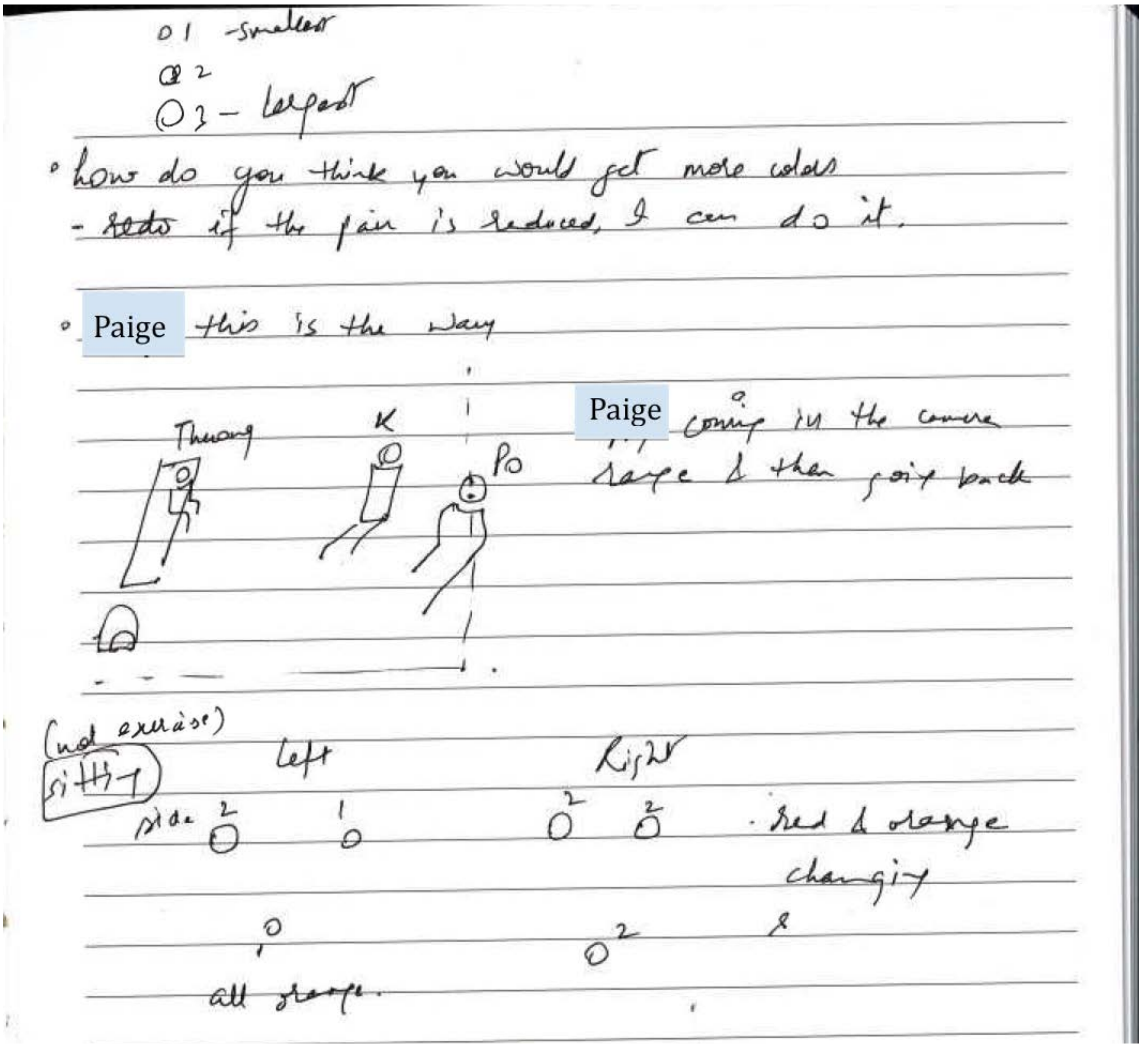
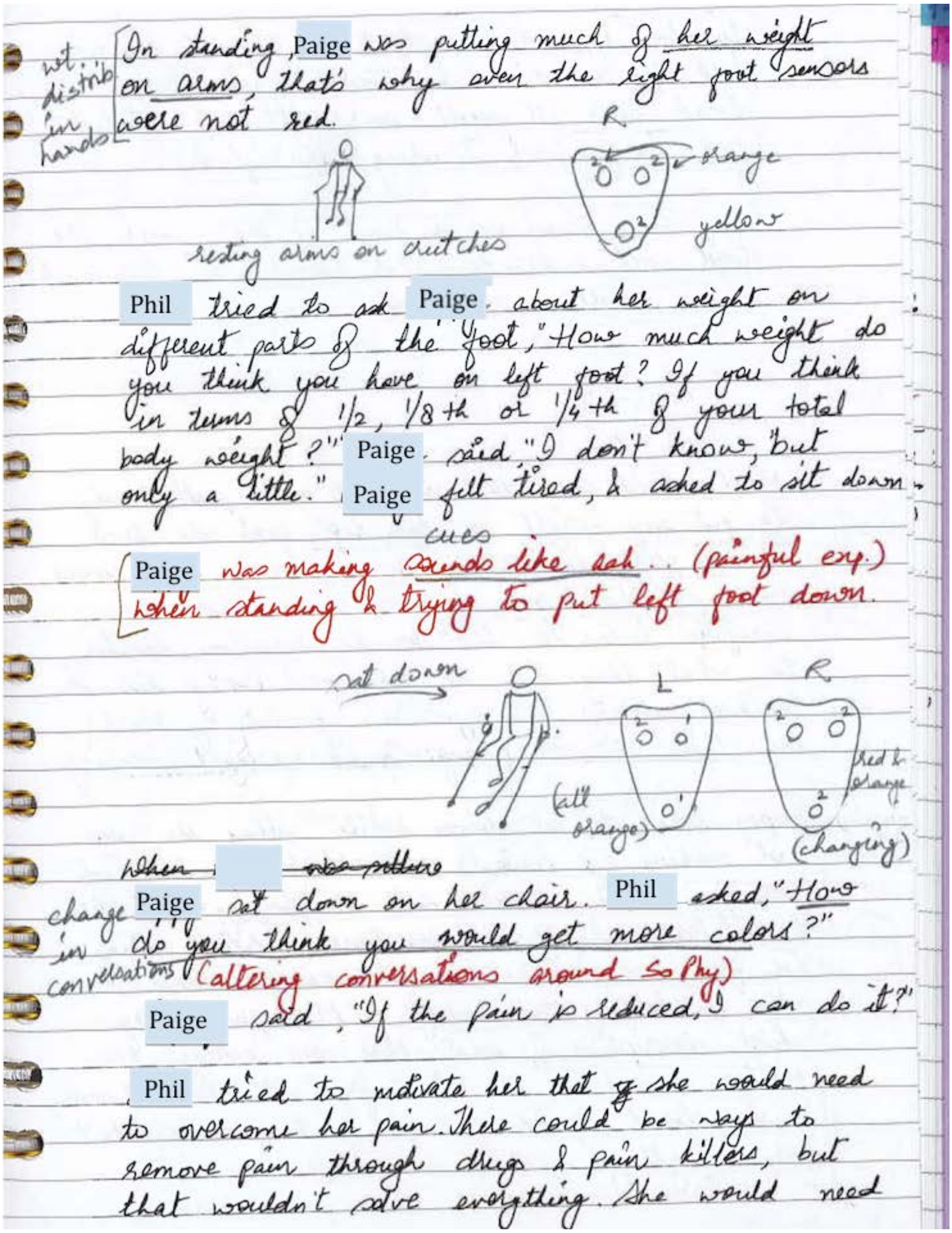


Figure: A snapshot of the short notes taken during the consultation.

Immediately after the consultation, these shorthand notes were elaborated to generate a descriptive account of the events that unfolded during the consultation. I used different color pens and pencil to highlight interesting events of the session. the following image shows how the above-mentioned shorthand notes from session 4 were transcribed.


wt. distrib in hands

On standing, Paige was putting much of her weight on arms, that's why even the right foot sensors were not red.

resting arms on crutches

R

orange

yellow

Phil tried to ask Paige about her weight on different parts of the foot, "How much weight do you think you have on left foot? If you think in terms of 1/2, 1/8 th or 1/4 th of your total body weight?" Paige said, "I don't know, but only a little." Paige felt tired, & asked to sit down.

cues

Paige was making sounds like aah.. (painful exp.) when standing & trying to put left foot down.

sat down

L

R

(all orange)

red & orange

(changing)

~~When was sitting~~

change in conversations

Paige sat down on her chair. Phil asked, "How do you think you would get more colors?" (altering conversations around so Phy)

Paige said, "If the pain is reduced, I can do it?"

Phil tried to motivate her that if she would need to overcome her pain. There could be ways to remove pain through drugs & pain killers, but that wouldn't solve everything. She would need

Figure: A snapshot of the elaborated field notes developed after the consultation.

D.5. Interview Guide

This document presents the interview guide that was used to interview clinicians and patients in the study. The interview guide was a part of the ethics application approved by the Ethics Advisory Group at the Royal Children's Hospital. This document was referred to in Section 7.4.5 and in Section 7.4.6.

Interview Guide for Clinicians

As the focus of the study shifted to the efficacy model, I revised interview guide for clinicians to include questions around different aspects of the efficacy model relevant for the study. Besides, I also added questions related to the technical issues with *SoPhy* and other questions regarding the future applications of *SoPhy*. Below I list the questions developed to interview physiotherapists after the consultation. This list included all the possible questions to ask with the physiotherapist, however all questions were not asked in each interview. The guide was appropriated in every session to make the questions relevant for the events just happened in the session. To achieve so, I printed a fresh copy of this list for each session. Also, when I was taking field notes, I marked appropriate questions to ask from the physiotherapist after the session, and also added new questions about certain events of the session that were not clear to me.

Topics	Interview Questions
Starters	○ How did you find using *SoPhy* in this session? ○ How would you compare this video session with your earlier sessions? ➢ What was different? ➢ What did *SoPhy* add in the consultation? ○ Can you walk me through the complete session and tell me about how did you use *SoPhy* at different times of the session? ➢ In the beginning (opening) ➢ When the patient described the symptoms (history taking) ➢ For examination ➢ For suggesting your diagnosis ➢ For the treatment ➢ And in the closing
Diagnostic Accuracy	○ How did use the information related to: ➢ Weight distribution

	➢ Range of movement ➢ Foot orientation ○ Were there any instances where the web-interface was particularly helpful? ○ Were there any instances when the information on web-interface did not match with your observations? What did you think about the reading then?
Diagnostic thinking	○ Did *SoPhy* influence your confidence in assessing this client? How? ○ Was there any difference in the number of repetitions for exercises performed with *SoPhy*? What was the reason behind it?
Therapeutic Efficacy	○ What sort of exercises did you try with *SoPhy*? ○ Did you try out these exercises for the first time with the client? ○ How did you use *SoPhy* during these exercises? (e.g., to explain the patient or to assess the patient's recovery) ○ How would you work with these exercises in standard video consultations without *SoPhy*? ○ What were you aiming to achieve for the client from this session? ➢ Were you able to achieve these goals? How?
Patient Outcome	○ How do you think *SoPhy* help this client? ○ What kind of conversations did the patient raise because of *SoPhy*? ○ Consider if you were not using *SoPhy* in this consultation, how would the patient raise such conversations? ○ What issues did this client face in using *SoPhy*?
Miscellaneous	○ How confident did you feel in using *SoPhy* in this session? ○ How would you define your overall satisfaction with *SoPhy* so far? ○ What technical issues did you face in using *SoPhy* in this session? ○ When was *SoPhy* most helpful for this client in this session? ➢ Assessment or treatment or both ○ How would you want to use *SoPhy* in future? ➢ assessment vs. treatment ➢ for acute pain condition vs. low pain ➢ foot issues vs. lower leg issues ➢ in video consultation vs. face-to-face consultation ➢ future sessions with the same patient ➢ For other patients? ○ Do you have any suggestions for improving *SoPhy*?

Interview Guide for Patients

Below I present the interview guide used to interview the patients. This guide was developed considering that patients would not have much time for the interview, and only a short interview would be possible with them.

1. How did you find using *SoPhy* in this session? (starting question)
2. How was it different from your last session when you used *SoPhy* in face-to-face setting?
3. How did *SoPhy* help you?
4. How did you use the information presented on the web-interface?
5. Did *SoPhy* increase your understanding of weight bearing? How?
6. What difficulty did you face in understanding the web-interface?
7. How do you think *SoPhy* could be useful for you in future?
8. Do you see any benefits of using *SoPhy* at home? Can you explain how.

D.6. Snippets of the Data Analysis Process

This document provides details of the early iterations of data analysis for Study 3. This document is referred to in Section 7.4.6 of the thesis.

The analysis in this study was guided by the findings of Study 1, with the aim of addressing the challenges observed in standard video consultations practise through *SoPhy* in Study 3. In pursuit, I compared the data of Study 3 with Study 1 after every consultation. I developed two tables, one comparing the findings, and another comparing the bodily information in both studies. However, after conducting four sessions of the study, the comparison became more concrete and I developed the following two tables. The following table compares the findings of Study 1 and Study 3. I positioned the comparing findings opposite to each other to highlight what challenge is resolved through *SoPhy* and what is not. This iterative comparison helped me to reflect on what data I had already collected and what else I need to know to resolve the challenges.

Phases	**Challenges related to Video Consultations (Findings of Study 1)**	**Influence of SoPhy on video consultations (Findings of Study 3)**
Opening		F1: First interactions with *SoPhy*/ Introducing *SoPhy* into clinical practise F2: Managing/Negotiating the spatial arrangement around *SoPhy*
	C1: Limited availability of incidental cues	F3: Greater understanding of incidental cues
	C2: Limited opportunities for small talk	**N/A**
History Taking	C3: Reliance on verbal explanation to understand symptoms	F3: Visualisation further elaborated patient's symptoms
	C4: Inability to Control Webcam's Field-of-View Caused Awkwardness to Patients	**N/A**
	C5: Subtle differences in exercises were difficult to observe	F4: Subtle differences in the movements were distinguishable
Examination & Diagnosis	**C6: Hands-on examination was not possible**	**N/A**
	C7: Environmental probes were	**N/A**

	out-of-view	F5: Contradictory behaviours of patients were revealed F6: *SoPhy* corrected clinician's assessment in some cases F7: Early confirmation on patient's progress boosted clinician's diagnostic confidence/ *SoPhy* boosted clinician's confidence in assessment
Treatment	C8: Limited scope to recommend new exercises	F8: *SoPhy* quickly became a common communication language F9: Early confirmation encouraged new strategies for treatment F10: Visual feedback made therapy more intuitive for patients F11: *SoPhy* became a therapeutic tool for weight bearing issues
Ending	C9: No room to accommodate afterthoughts	F12: Discussing afterthoughts

Similarly, I developed a table comparing the availability of bodily information between Study 1 and Study 3 to understand the influence of *SoPhy* in Study 3. However, this table was discarded later on, as comparing bodily information in two different studies was misleading. For instance, some bodily cues were different because of different patients – different attitudes and different patient condition. For example, in study 3, there was very little physical examination but in study 1, some sessions were dedicated to physical examination. Additionally, some bodily cues emerged because of the presence of *SoPhy*, e.g., hand gestures to *SoPhy* interface in face-to-face consultations. Whereas, some others bodily cues like eye contact was used throughout the session, however, it was not important for specific events listed in the findings. As such, this table was meaningful only with the narrations, as it offered a context to these bodily cues. The following table shows the comparison of bodily cues in Study 1 and Study 3.

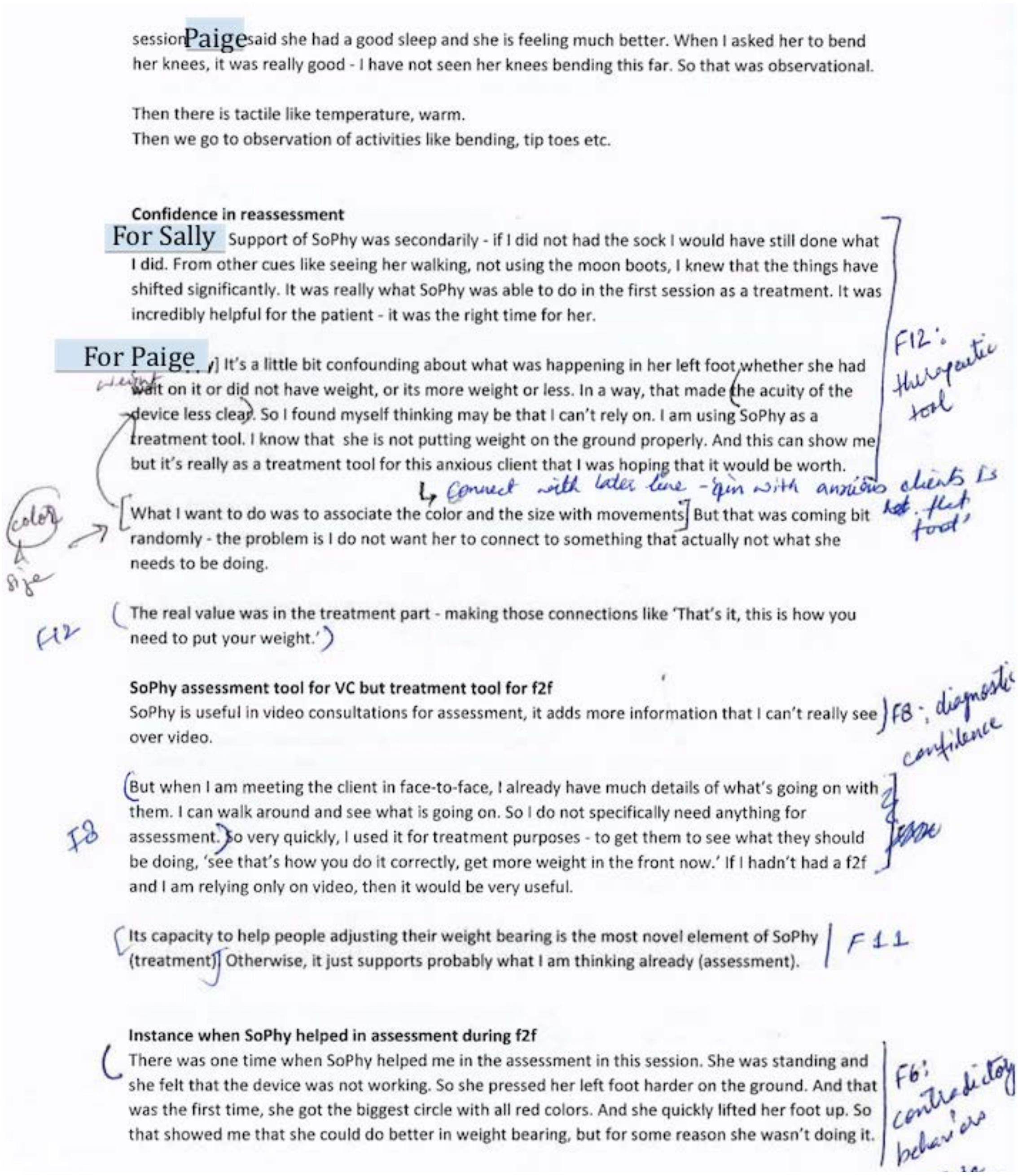
Bodily cues available in across six phases of consultation

		FACE-TO-FACE		VIDEO CONSULTATION	
Phases	Bodily cues	Study 1	Study 3	Study 1	Study 3
Opening	Movements	walking, sitting	walking, sitting, bending	×	sitting, bending
	Details of movements	×	weight distribution	×	weight distribution
	Quality of Movements	hesitation	hesitation, fluidity	×	hesitation
	Posture	full body	full body	upper torso	upper torso, feet arrangement
	Spatial arrangement	w.r.t. others	w.r.t. others and SoPhy interface	×	×
	Orientation*	full body	Full body	Upper torso	Upper torso + feet
	Eye gaze	×	×	×	w.r.t. two screens
	Appearance*	full body	Full body	upper torso	Upper torso + feet
	Hand gestures	×	to SoPhy interface	×	×
History Taking	Movements	exercises	exercises	exercises	exercises
	Details of movements	range of movement, weight distribution, depth of squats	range of movement, weight distribution, foot orientation, foot strike patterns	range of movement	range of movement, weight distribution, foot orientation, foot strike patterns
	Quality of Movements	fatigue	consistency, hesitation	smoothness	consistency, smoothness
	Posture	full body	full body	full body	full body
	Spatial arrangement	w.r.t. others	w.r.t. others and SoPhy interface	w.r.t. webcam	w.r.t. webcam
	Eye gaze	×	×	×	w.r.t. two screens
	Eye contact	encouragement	<tricky – has many purposes>	encouragement, willingness to engage	<tricky – has many purposes>
	Facial expressions	tears, redness on cheeks, tensed eyes	×	tensed eyes	×
	Tone of speech	heaviness	×	hesitation, pitch	×
	Hand gestures	×	to SoPhy interface	to describe pain	×
Examination & Diagnosis	Movements	twisting patient's body sideways	exercises	twisting body sideways through instructions	exercises
	Details of movements	×	weight distribution, foot	×	weight distribution, foot

			orientation		orientation
	Quality of Movements	×	efforts	×	efforts
	Touch	to patient body	to patient body	to own body	to own body
	Tactile feedback	body tightness, inflammation, skin temperature	body tightness, inflammation, skin temperature	×	×
	Response to touch	fear, protective spasm	×	×	×
	Pain characteristics	applied pressure, pain location, breathing pattern	verbal complaints	breathing pattern	groaning sounds
Treatment	**Movements**	exercises	exercises	limited exercises	exercises
	Details of movements	×	weight distribution, foot orientation	×	weight distribution, foot orientation
	Quality of Movements	fatigue	consistency, hesitation	×	consistency, hesitation
	Posture	full body	full body	×	full body
	Spatial arrangement	w.r.t. others	w.r.t. others & SoPhy interface	×	w.r.t. webcam
	Eye gaze	×	×	×	w.r.t. two screens
	Facial expressions	eyes tensed	anxiety, concentration	×	anxiety, concentration
	Multi-sensorial stimulus	×	✓	×	✓
	Hand gestures	to own body & patient body	to others & SoPhy interface	to own body	to own body
	Touch	to patient body	to patient's body & SoPhy interface	to own body	to own body, to webcam
	Tone of speech	emphasis	×	emphasis, low pitch	×
Closing	**Movements**	walking	bending	×	bending
	Quality of movements	hesitation	smoothness	×	smoothness
	Posture	full body	full body	×	full body
	Facial expressions	✓	✓	✓	✓
	Tone of speech	×	✓	×	✓

D.7. Coding of the Interview Data

This document provides details on the coding process of the interview data. The document is referred to in Section 7.4.6 of the thesis. The first phase of coding happened while transcribing the interviews, where I gave topic sentences to different sections of the interview. These transcripts were then printed for the next iterations of the coding, where I added more descriptive codes that best described the quotations. The following snapshot is taken from the interview with Phil, where he compared the use of *SoPhy* with Sally and Paige.


session Paige said she had a good sleep and she is feeling much better. When I asked her to bend her knees, it was really good - I have not seen her knees bending this far. So that was observational.

Then there is tactile like temperature, warm.
Then we go to observation of activities like bending, tip toes etc.

Confidence in reassessment

For Sally Support of SoPhy was secondarily - if I did not had the sock I would have still done what I did. From other cues like seeing her walking, not using the moon boots, I knew that the things have shifted significantly. It was really what SoPhy was able to do in the first session as a treatment. It was incredibly helpful for the patient - it was the right time for her.

For Paige It's a little bit confounding about what was happening in her left foot whether she had wait on it or did not have weight, or its more weight or less. In a way, that made the acuity of the device less clear. So I found myself thinking may be that I can't rely on. I am using SoPhy as a treatment tool. I know that she is not putting weight on the ground properly. And this can show me but it's really as a treatment tool for this anxious client that I was hoping that it would be worth.

What I want to do was to associate the color and the size with movements. But that was coming bit randomly - the problem is I do not want her to connect to something that actually not what she needs to be doing.

The real value was in the treatment part - making those connections like 'That's it, this is how you need to put your weight.'

SoPhy assessment tool for VC but treatment tool for f2f

SoPhy is useful in video consultations for assessment, it adds more information that I can't really see over video.

But when I am meeting the client in face-to-face, I already have much details of what's going on with them. I can walk around and see what is going on. So I do not specifically need anything for assessment. So very quickly, I used it for treatment purposes - to get them to see what they should be doing, 'see that's how you do it correctly, get more weight in the front now.' If I hadn't had a f2f and I am relying only on video, then it would be very useful.

Its capacity to help people adjusting their weight bearing is the most novel element of SoPhy (treatment). Otherwise, it just supports probably what I am thinking already (assessment).

Instance when SoPhy helped in assessment during f2f

There was one time when SoPhy helped me in the assessment in this session. 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. And she quickly lifted her foot up. So that showed me that she could do better in weight bearing, but for some reason she wasn't doing it.

Appendix E
Publications During Candidature

Overview: This appendix contains all peer-reviewed publications that arise from the research described in this thesis. This appendix is referred to on page 5 of the thesis.

E.1 presents the publication in the Conference on Human Factors in Computing Systems (CHI 2016)

E.2 presents the publication in the Conference on Designing Interactive Systems (DIS 2016)

E.3 presents the publication in the Conference on Human Factors in Computing Systems (CHI 2017)

E.4 presents the publication in the Conference on Human-Computer Interaction (INTERACT 2017)

E.1. Conference on Human Factors in Computing Systems (CHI 2016)

This document presents the extended abstract published in the ACM Conference on Human Factors in Computing Systems, CHI 2016. This publication resulted from the findings of Study 1 and was presented at the Doctoral Consortium venue of the conference. The full citation of the paper is:

Aggarwal, D., 2016. Supporting Bodily Communication in Video-based Clinical Consultations. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, CHI EA '16. ACM, New York, NY, USA, pp. 188–192. https://doi.org/10.1145/2851581.2859019

Supporting Bodily Communication in Video based Clinical Consultations

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Abstract
Over the last two decades, video consultations have emerged as an effective practice to offer diagnostic and therapeutic advice to the patients living in rural and remote areas. This thesis aims to understand how bodily expressions such as eye gaze and postures are communicated over video; and how can we design technologies that can communicate such essential information between clinicians and patients. As such, the thesis intends to augment the space of video consultations beyond video medium through the use of computational technologies.

Author Keywords
Video communication; clinical consultation; health; bodily communication.

ACM Classification Keywords
H.4.3 Communications Applications: Computer conferencing, teleconferencing, and videoconferencing.

Research Situation
I am a 2nd year PhD candidate (total duration is 3 years) with Prof. Frank Vetere and Dr. Bernd Ploderer at the University of Melbourne, Australia. I have successfully confirmed my candidature in May 2015. As an interaction designer and information scientist, I am studying the interactions of clinicians and patients with

the underlying video communication technologies for clinical purpose; and identifying ways to improve the interaction through novel design. I have recently finished my first study and currently planning the second study. I will continue working on the second and third study until I submit my thesis by March 2017.

Context and Motivation

HCI has a long tradition in examining bodily communication in the context of video-mediated communication [2,5,10]. Bodily communication, in general, describes conscious and unconscious signs communicated through our body [1]. Examples of bodily expressions include eye contacts, head nods, facial expressions, gestures, posture, and spatial orientation. These signs are not only used to complement verbal communication (e.g., through nods and facial expressions) but they are also used to communicate without words (e.g., through the collaborative gesture of a handshake).

Previous works describe bodily communication as one of the essential parameters in clinical settings where the clinicians and patients exchange bodily cues to establish rapport, articulate the health issue and to treat the patients [6,7,11]. For instance, Heath [7] mentioned that during face-to-face consultations, clinicians maintain constant eye contacts with patients as it comforts the patient in describing their health issue. Additionally, spatial orientation of patients and clinicians with respect to each other as well as to other physical artifacts in the surroundings is also identified as crucial during face-to-face consultations [4].

Bodily communication is, however, limited in video consultations [12,13] that aims to connect patients and clinicians over-a-distance for the purpose of clinical advice. There exist some preliminary evidences that video communication in clinical setting also influences bodily communication in other ways. In this regard, Miller [9] pointed out the difficulties that patients face during video consultations in reading the posture of a clinician. For instance, a clinician - leaning forward - is perceived as concerned about the patient's health issue, whereas a clinician - leaning backward - implies the opposite to the patients. However, an understanding of the significance of other bodily cues, and their impact on clinician-patient interactions during video consultation is missing.

While the importance of bodily communication for face-to-face consultations is well-established, there is a lack of understanding of how bodily information is communicated in video consultations. Early work on video-mediated communication also illustrate that the video callers can reasonably adjust their verbal communication to overcome the limitations of bodily communication [2,8]. However, it is unclear whether and how such limitations and adjustments may impact video-based communication in a clinical setting, particularly, in yielding effective consultation outcome.

This work endeavors to identify and address the challenges in communicating bodily communication during video consultations. Such an understanding is essential to ensure that the introduction of new medium (video) does not hinder the specific needs of clinicians and patients. The thesis intends to encourage design thinking for developing video consultation systems that could enhance the clinician-patient interactions remotely.

Research Phases	Research Methods
Literature Review	Keyword based search for the related topics, methods and researchers within HCI and health
Study 1	Field study; Observation and semi-structured interviews for data collection; Inductive Analysis for analyzing data
Study 2	Lab based testing; Informal discussions to generate design strategy; Thematic coding for data analysis
Study 3	Field Deployments; Observation and semi-structured interviews for data collection; Thematic coding for data analysis

Table 1: Overview of the research methods used across different phases of the research.

Research Question

The main research question investigated in this research is: *How to design communication technologies that can support bodily communication during video based clinical consultations?*

The work began with the general investigation of the existing literature in HCI and health domain, with new ideas being formed and tested as I progressed with the research. The three main research objectives are described below, where each objective defines a separate study.

Objective 1) Understand the existing practices of video based clinical consultations with a focus on bodily communication between patient and clinician. Identify the challenges and design opportunities to communicate key aspects of bodily information over video. **Objective 2)** Identify or propose new design strategy to address the challenges found through Objective 1. **Objective 3)** Create and empirically evaluate a design prototype based on the design strategy devised in Objective 2.

Research Method

This research employs qualitative research practices to get deeper understanding of the video consultations. Table 1 provides an overview of the methods that will be used across the three studies. The first study is an exploratory field study that aims to investigate how bodily cues are communicated over video through semi-structured interviews and observations of video consultations (Obj.1). This study will highlight several design opportunities that I will explore in my second study. The second study aims to explore the design space of video consultation systems through informal discussions with clinicians, patients and designers (Obj. 2). Based upon the insights gained from the second study, I will design a research prototype that will be evaluated in the third study through field deployment in different clinical consultations (Obj.3). In the third study, I will evaluate the user experience with the proposed prototype through observations of video consultations and semi-structured interviews with participants. The study will highlight the issues and challenges that interactions with interactive technologies might bring up during video consultations.

Dissertation Status

In response to my first objective, I started observing video consultations in the domain of physiotherapy at a leading children's hospital in the city. To gain the background knowledge of the key aspects of clinical consultations and to understand the strengths of video consultations, I also observed face-to-face consultations for physiotherapy. Over a period of 8-months, I have observed 10 consultations: 7 video and 3 face-to-face. Along with multiple semi-structured interviews and informal discussions with clinicians and patients, the study revealed several interesting insights.

The study highlights that the clinicians rely upon a wide range of bodily cues related to body movements, postures, and tactile aspects of the patient's body. Clinicians observe the patient's bodily cues right from the start of the consultation, to get a complete picture of their health. Additionally, different bodily cues are relevant across different phases of the consultation: Opening, History Taking, Examination and Diagnosis, Treatment and Closing (as defined by [3]). These bodily cues are naturally available in face-to-face

Phase	Bodily information available in face-to-face consultation	Bodily information available in video consultation (unavailable cues over video are strikethrough)
Opening	Appearance, Facial expression, Movement (walking, sitting), Posture (orientation, engagement), Eye contacts (for attention)	Appearance, Facial expression, ~~Movement (walking, sitting)~~, Posture (orientation, engagement), Eye contacts (for attention)
History Taking	Facial expressions (tears, redness on cheeks, eyes tensed), Tone of speech, Hand gestures (to others and own body), Body movements (depth of squats, hesitation, fatigue), Eye contacts	Facial expressions (tears, redness on cheeks, eyes tensed), Tone of speech, Hand gestures (~~to others~~ and own body), Body movements (~~depth of squats~~, hesitation, ~~fatigue~~), Eye contacts
Examination & Diagnosis	Tactile feedback (body tightness, inflammation, skin temperature), Response to touch (fear, protective spasm, facial expressions), Eye contacts	~~Tactile feedback (body tightness, inflammation, skin temperature)~~, ~~Response to touch (fear, protective spasm, facial expressions)~~, Eye contacts
Treatment	Postures, Body movement (fatigue, flexibility), Facial expression (eyes stressed), Eye contacts	~~Postures~~, ~~Body movement (fatigue, flexibility)~~, Facial expression (eyes stressed), Eye contacts
Closing	Facial expressions, Body language, Eye contacts	Facial expressions, ~~Body language~~, Eye contacts

Table 2: Different aspects of bodily expressions are available across different phases of face-to-face and video consultations.

consultations; However, some of these cues get missed over video. The lack of these bodily cues limited the information space of the clinicians. Consequently, clinicians relied more upon the verbal elaboration of the patient, which did not fulfill the needs aptly. Table 2 provides a summary of the bodily cues that are available in face-to-face and video consultations across different phases of a physiotherapy consultation.

The insights gained from the first study have opened up four design dimensions that will guide my second and third studies. These dimensions speak to: 1) accommodating asymmetries of the roles and responsibilities underlying in the clinical setting; 2) expanding the perspectives of video consultations both in terms of field view and time; 3) augmenting visual acuity with computational (non-visual) technologies; and 4) using sensing technologies to communicate essential tactile information.

Expected Outcomes

The thesis intends to make the following contributions: (1) provide evidence of what aspects of bodily communication are required for clinical assessments in physiotherapy but are not supported by video technologies; (2) highlight opportunities to inform the work of the researchers and designers creating applications for clinical settings; and (3) invoke interests in expanding video consultations from video medium to other computational technologies that can track and communicate the essential bodily cues remotely.

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E.2. Conference on Designing Interactive Systems (DIS 2016)

This document presents the full paper published in the ACM conference on Designing Interactive Systems, DIS 2016. This publication resulted from the findings of Study 1 and was presented at the conference. The full citation of the paper is:

Aggarwal, D., Ploderer, B., Vetere, F., Bradford, M., Hoang, T., 2016. Doctor, Can You See My Squats?: Understanding Bodily Communication in Video Consultations for Physiotherapy. In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems.* ACM, pp. 1197–1208. DOI: https://doi.org/10.1145/2901790.2901871

Doctor, Can You See My Squats?: Understanding Bodily Communication in Video Consultations for Physiotherapy

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ABSTRACT
This paper investigates the challenges of bodily communication during video-based clinical consultations. While previous works describe the lack of eye contact and gestures over video, it is unclear how these limitations impact the course of a clinical consultation, particularly in a domain like physiotherapy where the focus is on improving body movements and functioning. To contribute to this understanding, we conducted observations of 10 naturally occurring video and face-to-face consultations for physiotherapy. We found that clinicians rely on a variety of incidental bodily cues and fine-details of body movements to assess and examine the patient. These bodily cues were noticeable during face-to-face consultations; however, a variety of bodily cues got missed over video. Consequently, video consultations became conversational where the clinicians used verbal conduct to get a fair understanding of the patient's health. To guide design of future video consultation systems, we reflect on our understanding as 4 design sensitivities: Visual Acuity, Field-of-view, Clinical Asymmetries, and Time Sequence.

Author Keywords
Video communication; clinical consultation; health; physiotherapy; bodily communication; nonverbal communication.

ACM Classification Keywords
H.4.3 Communications Applications: Computer conferencing, teleconferencing, and videoconferencing.

INTRODUCTION
Bodily communication is defined as a crucial aspect of clinical consultations. In a clinical setting, bodily communication is used to establish rapport, to articulate the health issue and to suggest the treatment during a clinical discourse [21,22,24,35]. For instance, patients often find it hard to clearly describe their bodily symptoms orally and instead rely on nonverbal cues such as eye gaze, facial expression, and body language to communicate their feelings [21,22]. Clinicians, on the other hand, keenly observe such cues to understand patient's emotional and physical wellbeing [21]. For example, a physiotherapist pays attention to the patient's distorted and careful movements to check patient's recovery [4,28]. Similarly, a psychiatrist makes use of patient's abnormal body language, pale face, and hesitation in speaking to understand their stress level [13].

Due to the growing needs to support health services at remote geographical locations, video based consultations have emerged as a viable approach to offer clinical consultations to remote patients [41,44]. So far, the focus of video consultations has remained on establishing audio and video connections between clinician and patient to discuss varied health domains [5,12,13,15]. However, such an audio-video approach on clinical consultations might not be sufficient in supporting all the essential clinician-patient interactions, particularly, the ones that happen through bodily communication. For instance, it is unknown how a physiotherapist sees the distorted movements of their patients over video.

Studying video consultations becomes crucial as prior works in non-clinical settings suggests that certain bodily cues get missed when we move our conversation from physical space to video [14,18,23,31]. For instance, these works suggest that video callers face difficulties in communicating eye gaze, spatial orientation, and hand gestures over video. In response, they adjust their verbal conduct to communicate the intended meaning. However, what remains unclear is whether and how the diminished bodily communication influences the clinician-patient interactions during video consultations. While adjustments through verbal communication can be made, they may not be sufficient for an effective consultation outcome.

This research aims to understand the significance and challenges of bodily communication during video consultations. We chose physiotherapy as a first domain of inquiry because of the increased demand and growing practice of video-based physiotherapy within Australia [1]. We report on 10 naturally occurring video and face-to-face consultations for physiotherapy that were organized by the clinicians to address their patients' needs. We highlight

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nine challenges that clinicians faced in interpreting patient's bodily cues across six phases of video consultation.

This paper makes four core contributions. Firstly, the paper extends the literature on clinical consultations by offering the first conceptual understanding of how bodily communication is employed across six phases of physiotherapy related consultations. To this end, our work extends the established phases of face-to-face consultations [6] to define the course of video-based consultations. Secondly, this work expands our understanding of video-mediated communication by describing nine challenges that clinicians faced in understanding bodily information during video consultations. Thirdly, we contribute to the knowledge of bodily communication by providing a detailed narration of the bodily cues used to fulfill varied routines of physiotherapy consultations. Finally, through identifying four design sensitivities, we point to new directions for video consultations that make use of other computational technologies.

RELATED WORK

Argyle [3] defined bodily communication as the conscious and unconscious non-verbal signals that we use to serve five purposes during social encounters: 1) to express emotions through facial expressions, and gaze; 2) to support our speech using paralinguistic qualities such as pitch, stress, and hesitations; 3) to represent self through different aspects of appearance and body language; 4) to communicate the interpersonal attitudes through touch and gaze; and 5) to fulfill the rituals of a social setting through spatial orientation and gestures. These non-verbal cues are closely intertwined with verbal conversations and are best understood in the given context. William et al. [45] further highlight the importance of bodily communication by suggesting that 55% of our conversation happens through bodily cues and the rest is contributed by verbal conduct.

We discuss the existing literature on face-to-face and video consultations around bodily communication to establish the background for the study.

Bodily Communication in Face-to-Face Consultations

A face-to-face clinical consultation happens between co-located patient and clinician. In such face-to-face setting, bodily communication not only enhances the overall communication between patient and clinician, but also help in gradually succeeding the consultation through different phases [21,22]. Based on the type of activities that clinicians perform, a typical face-to-face consultation is categorized into the following six distinct but overlapping phases [7]:

1. **Opening** – A face-to-face consultation starts with an *opening phase*, where clinician attempts to build a rapport with the patient through informal conversations.
2. **History Taking** – Once the rapport is established, the clinician extends the consultation to the second phase of *history taking*. Clinician attempts to discover the reasons behind patient's attendance. Patient puts forward their health related complaints, and updates the clinician with the results of the ongoing treatment.
3. **Examination** – After listening to the patient's medical history, consultation proceeds to the third phase of *examination*. The clinician conducts a verbal and/or physical examination of the patient to understand the health issue.
4. **Diagnosis** – The fourth phase is of *diagnosis* where the clinician explains the outcome of examination to the patient and discusses the potential causes and effects of the underlying health condition.
5. **Treatment** – After the diagnosis, *treatment* phase begins. The clinician suggests a medication or therapy to the patient to recover from the current health issue.
6. **Ending** – Finally, the clinician terminates the consultation through small talk and schedules a next appointment, if required.

Bodily communication is critical across all phases of a consultation [21,22,24,36]. For instance, in the opening phase, patients take frequent pauses while describing their health issue to check if the clinician is following them or not. Clinicians also use bodily gestures such as head nods to acknowledge their participation in the dialogue and to encourage patients to elaborate further. Additionally, clinicians maintain constant eye contact with patient to make them comfortable in discussing their health issue [22]. Moreover, appropriate spatial orientation of clinician with respect to patient is also considered critical in inviting patient's participation in the discussion [8,24].

During subsequent consultation phases, clinicians observe a series of bodily cues to understand the underlying health issue and its severity [22]. For instance, the cracking sound in breathing, vibrating gesture near the mouth, and efforts in speaking altogether illustrate the patient's health issue. Clinicians pay attention to these fine-details to diagnose the disease along with other visible aspects such as skin color [33]. As such, clinicians utilize varied bodily cues of the patient to interpret the underlying health issue and to understand the patient's sufferings. While, on the other hand, patients utilize the clinicians bodily information to develop trust in the clinician and in the overall treatment.

Bodily Communication in Video Consultations

Video consultations (or teleconsultations) are forms of clinical consultations where distantly located clinicians and patients utilize video conferencing tools for the purpose of diagnostic or therapeutic advice [43,46]. Over the last two decades, video consultations have become a popular approach for patients living in remote areas and having mobility issues. Previous works [15,16,31] have explored validity and technical feasibility of video consultations in supporting a variety of clinical domains such as speech pathology [2] and surgery [39]. As yet, the advancements in such systems have been the shift from desktop computers to mobile devices (e.g., tablets and phones) and the increase in network bandwidth to allow better quality video and audio streaming [5,12,13]. We argue that these advancements in audio and visual technology can fairly supported clinical consultations in domains like dermatology where the relevant health concern is directly visible on body. However, its applicability to domains like physiotherapy can be questioned where the assessment heavily relies on the fine-grained details of patient's body movements. Recent works in HCI have explored the potential of Kinect based tracking [27,41] and aural feedback [38] to get details of patient's movements during exercise. However, these advancements will need in-depth exploration and maturity before they can be used in real-time video consultations.

In the context of video consultations, Miller [30,31] provided a preliminary understanding of the importance of bodily communication. He indicated that patients try to understand clinician's engagement in the ongoing video conversation through their body language. For instance, a clinician, leaning forward, is perceived as concerned about the patient's health issue; whereas a clinician, leaning backward, implies the opposite to the patients. Miller [30] also stated that during a video consultation, clinicians spend less time in socializing (e.g. having informal talks) and converse directly about the patient's health concern. Additionally, the video medium also limits opportunities for haptic interactions with the clinician, which patients always find as comforting according to Placebo Effect [9]. The lack of interpersonal moments and social interactions during video consultations are described as potential risks in establishing an empathetic relationship between clinician and patient [30,40].

Learning from previous works on video communication in non-clinical setting, we know that video callers miss out certain bodily cues such as hand gestures, eye gaze and spatial orientation during video conferencing [14,18,23,32]. However, such bodily cues are always emphasized as crucial part of clinician-patient interactions during face-to-face consultations [21,22]. This raises the need to understand whether video technology can support the essential bodily information required to accomplish different clinical tasks. Such an understanding is required to ensure that the introduction of video technology does not hinder the specific needs of clinicians and patients, and to guide the design of future technologies that could further enhance the clinician-patient interactions.

FIELD STUDY

The aim of this study is to investigate the role of bodily communication in video consultations, and to identify the challenges in communicating such information over video. To achieve our goals, we conducted a qualitative field inquiry of both video and face-to-face consultations for physiotherapy. We also studied face-to-face consultations in order to understand the differences in clinician-patient interactions during video consultations. Studying face-to-face consultations provided us with background knowledge on how a consultation for physiotherapy happens in a natural environment, and what are the essential activities of a consultation. We utilized this understanding to compare the strengths and limitations of video technology to support the required clinician-patient interactions. Ethics to conduct this study was approved by the ethics committee of the hospital and the university.

Research Context

The study was conducted in collaboration with the Pain Management Team at Royal Children's Hospital, Australia over a period of 8 months. We chose to study physiotherapy for chronic pain as a first domain of inquiry because of its growing rate within Australia: chronic pain is the third most costly health condition and nearly 30% of children suffer from it [34]. Chronic pain is also a long-term condition where patients continue seeing physiotherapists for months or years, which can severely disrupt education, work life and social connections with peers [25]. This is particularly significant, as some patients from our study had to travel as far as 4000km to visit the hospital. In response to these community needs, the hospital started to offer video consultations for physiotherapy from past 2 years. Our research was, thus, partially inspired by the local need and emerging practice at the hospital.

Study Setup

We observed 10 naturally occurring consultations organized by 2 physiotherapists: Phil and Paul, for 5 patients: Anna, Jenny, Laura, Camilla, and Susan (names changed). All patients aged between 10-17 years and were having varied chronic pain symptoms: Anna and Jenny had pain in multiple body parts, Laura had pain in her ankle, Camilla had shoulder pain, and Susan had pain in her head. Table 1 enumerates all sessions in the order of their occurrence over 8 months. All consultations were follow-up consultations. Besides the patient and clinician, the consultations involved other people at different times as mentioned in Table 1. All face-to-face consultations happened at the hospital. We observed the video consultations from the clinician's side at the hospital, while patients joined in the video consultations from their home (sessions 1, 6, 8-10), or from the local hospital with their GP (sessions 4 & 5).

The physiotherapists used the following devices during video consultations: a desktop computer with webcam, laptop, telephone and speaker. The hospital department has a dedicated room to organize video consultations where two computer screens and a telephone are placed together on a table. Both clinicians used only one screen for organizing the video consultations, except for the last session where Phil used both the screens. Telephone was used to call patients when there were issues in the video call. Patients, on the other hand, used their laptop as it offered flexibility of moving the camera according to their needs. Furthermore, GoToMeeting [19] and HealthDirect [20] software were used to make video calls. Both the video and face-to-face consultations went for around 60 minutes.

Session	Type of Consultation	Child (patient)	Others at patient end	Physiotherapist	Others at clinician end
1	Video	Anna	Mother	Phil	Pain Consultant
2	Face-to-face	Anna	Mother, Father	Phil	Occupational Therapist, Psychologist
3	Face-to-face	Anna	Mother	Phil	Psychologist
4	Video	Anna	Mother, GP	Phil	--
5	Video	Laura	Mother, GP	Phil	--
6	Video	Anna	Mother	Phil	Occupational Therapist
7	Face-to-face	Laura	Mother	Phil	Pain Consultant, 2 Trainees
8	Video	Camilla	--	Phil	Telehealth Manager
9	Video	Jenny	Mother	Paul	--
10	Video	Susan	Mother, Father	Phil	--

Table 1: Details of the observed consultations in the order of their occurrence. These sessions were observed by the first author from the physiotherapist's end. (Names of the participants are changed to preserve anonymity.)

Methodology

Our research methods were informed by the sensitivity of the clinical setting and the hospital ethics guidelines. For instance, since the consultations were organized for young patients (under 18 years) with chronic health conditions, we aimed to keep the setting naturalistic and comforting. We, therefore, did not video-record the sessions nor did we photographed the participants. Additionally, as the patients were located in remote areas, the hospital's ethics committee only allowed observations from clinician end, which reduced our option to observe video consultations from the patient end.

We recruited clinicians based on their practice of organizing video consultations, while clinicians recruited patients as per their health conditions. Also, to reduce the variation in communication style and practices of every clinician, we observed video and face-to-face consultations with same clinicians. Additionally, we aimed to observe the same patients repeatedly in order to understand the suitability of video and face-to-face consultations at different times.

In line with the challenges discussed by Blandford et al. [6], we faced several challenges in studying video consultations that limited our data collection and stretched our study to 8 months. We briefly discuss four key methodological challenges. Firstly, since video consultation is a relatively new practice, most clinicians do not choose to undertake a video consultation. For those that do, their patients do not always agree. Thus, finding a suitable clinician-patient pair that utilizes video consultation was difficult for us. Secondly consultation sessions are structured around the patient's needs. Thus, the consultation frequency for each patient can vary from weekly to several months. Thirdly, video consultations often involve clinicians from different hospitals at remote ends. Their participation in the study might require separate ethics approval from the respective hospital, which is not always feasible given the lengthy process of obtaining ethics approval. This further limited our access to video consultations. Finally, consultations involving vulnerable patients or sensitive conversations are typically not open for observation. Together, these challenges create a complex research environment, which needed to be approached with care and sensitivity.

Data Collection

In line with earlier studies [6,8], we used three methods to collect rich data: participant observations, semi-structured interviews and informal conversations.

The first author conducted observations of 10 video and face-to-face consultations. The sample size is in line with the recent study on face-to-face consultations [29]. All observations were conducted from the clinician's end without causing any interruptions to the ongoing session. The researcher took field-notes during the consultation, which were elaborated later. Also, we took photographs of the setup (excluding participants) to understand the arrangement of underlying technology. Secondly, to understand the subjective experience with video consultations, we also conducted 10 semi-structured interviews: 7 with clinicians and 3 with patients (and caregivers together). Interviews varied from 20-40 minutes and were audio recorded.

Finally, we capitalized on every opportunity to have informal chats with participants to reflect upon the latest event in a think-aloud manner. With clinicians, we initiated conversation while they were setting up for the consultation, resolving technical issues during the session, and when the session was over. Similarly, we had informal conversations with patients and caregivers when they were waiting for the clinician, or while they were leaving the room after a face-to-face consultation. These conversations varied from a few minutes to even half an hour and were noted down as field-notes.

Data Analysis

Our data collection and analysis process were closely intertwined. We utilized Inductive Analysis [35] to iteratively collect and analyze the data. We also used Member Checking [37] with physiotherapists to validate and get feedback on the emerging themes. We went through several rounds of coding for our field notes and interview transcriptions, which started from the first day of data collection. The first author initially coded the data in the hand-written field notes. The emerging trends and themes were created as memos, and were discussed with other authors regularly to reflect upon the data. Lastly, we analyzed the data with the lens of bodily communication to identify patterns of bodily cues during video and face-to-face consultations. Based upon the relevance of bodily cues, we structured the key ideas across 6 known phases of face-to-face consultations [7]: Opening, History Taking, Examination & Diagnosis, Treatment, and Ending.

FINDINGS

Below we discuss the challenges of bodily communication in video consultations. Each challenge is marked with enumeration such as C1, C2 and so on. Within each challenge, we first narrate how bodily information was used in face-to-face consultations, and then we bring the contrast with video consultations. Table 2 lists the differences in bodily cues that are communicated across six phases of face-to-face and video consultations.

Phase 1: Opening

In this phase, clinicians checked for the following bodily cues of the patient: movement patterns, body posture, orientation and appearance.

C1: Limited Availability of Incidental Cues

During a face-to-face consultation, clinicians started their examination from the moment they see the patient as they walked into the consultation room. They checked a number of bodily signals related to walking, sitting, and talking style that patients communicated unconsciously. For example, in session 2 (face-to-face), Phil noticed Anna's posture as she sat cuddling to her front for the entire session. Similarly, in session 7 (face-to-face), Phil noticed that Laura did not rest her feet on the floor, whereas her feet were dispersed away from each other with only toes touching the floor. These body postures of Anna and Laura respectively indicated pain severity in their ribs and ankles. Clinicians also checked how the patient took their seat e.g., did they hesitate in sitting down because of pain. Furthermore, they checked the spatial arrangement of the patients with respect to others e.g., if they preferred to sit closer to their mother or father. From these observations, clinicians gained information related to the behavioral and emotional state of the patient.

On the other hand, a video consultation was more direct as the clinician saw the patient directly sitting in front of the camera. Consequently, clinicians failed to see some crucial bodily movements of the patient related to walking and sitting. However, clinicians then utilized other cues that were available over video such as body posture and orientation, to understand emotional and physical state of the patient. For instance, in session 9, Jenny sat in a way that she could see Paul (over video) but not her mother (sitting next to her), as she had her back towards her. This body orientation of Jenny illustrated emotional struggle between Jenny and her mother. Paul picked up this cue and tried to make Jenny aware of her responsibilities towards her parents.

C2: Limited Opportunities for Small Talk

We found that during face-to-face consultations, clinicians tried to build rapport with patients by initiating small talk around different topics such as weather, journey and their appearance. Clinicians introduced most of the informal conversation when the patient was entering or settling down in the consultation room. Having small talk not only helped the patient to open up with the clinician, but also provided information to the clinician related to the patient's emotional state. For instance, in session 3 (face-to-face), Phil gave Anna a complement on her new hair-style and tried to remember how the new style was different from her earlier one. Anna described how she changed her hair-style using hand gestures to show hair length, *"I do a change every time my pain gets severe. Earlier I had very long hair, then it was medium and now it is very short."* With this, Phil understood that Anna's pain had not changed much and that she was using different strategies to overcome her pain. Similarly, during session 7, the pain consultant invoked conversations around Laura's height by saying, *"Laura, have you grown up a bit? You look tall today."* Everyone started having a cheerful conversation on how she was looking in her last visit.

However, during video consultations, as everyone had already taken up their seats, there was a sense that clinicians should directly discuss the purpose of their meeting. Additionally, as the complete view of the patient was not available, clinicians did not get significant cues related to body movements, or (full body) appearance of the patient to spontaneously introduce small talk. Moreover, instead of having informal conversations, the video consultation started by making sure that the technology was working properly. And if there were issues, clinicians had to make alternate arrangements. Consequently, clinicians remained occupied and stressed in the beginning of the session, which, in turn, did not leave sufficient room to introduce short talk. However, clinicians tried to create a friendly environment by making jokes around the technical issues. For instance, in session 6 (video), Phil realized the delay in video streaming at Anna's end as he was getting his voice back. He then responded, *"Now if I tell you a joke, I will have to wait for a while to hear the laughter."* At other times, clinicians inquired about the technical issues in a funny way. For instance, in session 8, the telehealth manager asked Camilla about the video quality, *"How clear is the video? Can you see the wrinkles on my face?"*.

Phase 2: History Taking

During this phase, the essential bodily cues are facial expressions, tone of speech, hand gestures, eye contact and fine-details of body movements.

Phase No.	Phase	Bodily cues in face-to-face consultation	Bodily cues in video consultation
1	Opening	• Movement (walking, sitting) • Posture • Orientation • Appearance (**full body**)	• N/A • Posture • Orientation • Appearance (**upper torso**)
2	History Taking	• Facial expressions (**tears, red cheeks,** tensed eyes) • Tone of speech (hesitation, pitch) • Hand gestures • Eye contact (for encouragement) • Body movements (range of movement, smoothness**, weight distribution, depth of squats, fatigue**)	• Facial expressions (tensed eyes) • Tone of speech (hesitation, pitch) • Hand gestures • Eye contact (for encouragement, **willingness to engage**) • Body movements (range of movement, smoothness)
3, 4	Examination & Diagnosis	• Touch (**to patient's body**) • Tactile feedback (body tightness, inflammation, skin temperature) • Response to touch (fear, protective spasm) • N/A	• Touch (**to own body**) • N/A • N/A • Body Movements
5	Treatment	• Full body posture • Gestures (**to others**) • Touch (**to patient's body**) • Tone of speech (emphasis) • Body movement (fatigue) • Facial expressions	• N/A • Gestures (**to own body**) • Touch (**to own body**) • Tone of speech (emphasis, **pitch**) • N/A • N/A
6	Closing	• Facial expressions • Body language	• Facial expressions • N/A

Table 2: Bodily cues are communicated differently across 6 phases of face-to-face and video consultations. Text written in bold indicates the difference in bodily cues, while the text 'N/A' signifies the absence of a bodily cue.

C3: Elaborating Symptoms Require Vocal Expertise

During face-to-face consultations, clinician looked for different bodily cues that patient communicated while describing their symptoms. Phil explained that since pain is subjective, description of the same symptoms vary for different people. As a result, clinicians gave more emphasis to patient's bodily information than their vocal explanation. For instance, in session 2 (face-to-face), when Phil asked Anna about her pain, she said, "*Not so good*". She could not say anything more as she got overwhelmed. Her cheeks got red, her eyes were filled with tears, and her tone suddenly got heavy. Seeing these cues, Phil understood that her pain severity has not changed much.

However, the fine-grained details of the patients' facial expressions and other bodily cues were not always available over video. Clinicians therefore, majorly relied on the verbal explanation of the patient (or caregiver). For instance, during session 1 (video), Anna described her pain as fifty-fifty. She did not say anything else, but looked down. Anna's mother then described her pain symptoms with hand gestures. She moved her left hand up and down with great intensity and high frequency, to illustrate her pain characteristics. However, her hand movements did not completely fall in the camera range and thus were missed. Phil got a fair understanding of Anna's health through the verbal explanation and hand gestures of her mother. This limitation of video complicated the situation for patients who were not good in explaining things verbally. For instance, Laura was very shy and never participated in any conversation with Phil. Her expressions were always limited to binary answers on whether she was having pain in certain body parts or not. Phil, therefore, relied on her mother's verbal description. Although Laura's mother did a good job in describing her health issue, but Phil always missed the subjective information from Laura. As a result, Phil was reluctant in seeing Laura over video.

C4: Performing Certain Exercises Feel Awkward

During face-to-face consultations, patient showed a variety of exercises that they had been following from their last consultation. For instance, in session 7 (face-to-face), Laura performed a range of exercises that required her to lie down on the plinth, sat on the floor, laid on the floor against the wall, and bending against the wall. While the patients were performing the exercises, clinicians encouraged the patients by maintaining constant eye contact. At times, they also performed exercises with patients to make them comfortable. For instance, in session 7 (face-to-face), Phil realized that the presence of multiple clinicians could be intimidating for Laura as she was bit introverted. Therefore, to comfort her, they performed all the exercises together. As Laura was doing the exercises, Phil looked for the required bodily cues to check her improvement.

In video consultations, patients did not demonstrate all the exercises. They only showed a couple of them that clinicians asked for. Majorly, patients only performed the standing exercises such as tip-toes, and squats. However, there were instances when patients felt awkward to perform some particular exercises over video. For example, in session 8 (video), Phil asked Camilla to show her shoulder exercises that required her lying down on the bed. Camilla initially showed reluctance in doing the exercise and then bargained with Phil on the number of repetitions. Later in the conversation with observer, Camilla mentioned that she felt awkward to lie down on her bed during video consultation, which she thought was perfectly fine in face-to-face consultations. She then described that over video she did not get any proper feedback on how she was visible on camera as she was away from the camera. This unease was possibly because she was not sure if the camera was capturing her whole body or if it was more focused on certain body part. Additionally, as she was making the video call from her bedroom in the absence of any parent, the private setting might have added more to her awkwardness.

C5: Subtle Differences in the Exercises are Difficult to Observe

During face-to-face consultations, a clinician looks for subtle differences in the exercises of the patient e.g., depth of squats, range of arm movement, and weight distribution across different body parts. To this end, they moved around the patient to understand the angular differences, or the body postures. For instance, in session 3 (face-to-face), when Anna was doing squats against the wall, Phil moved from his chair and stood sideways to see how far she was bending. For other exercises that Anna was performing while sitting on the chair, Phil changed Anna's back from tilted to straight by pressing it while she continued doing the exercise. Similarly in session 7 (face-to-face), when Laura performed tiptoes, Phil checked fatigue in her legs through shivering and weight distribution over legs.

However, over video, observing subtle differences in the exercises was not straight-forward for the clinicians. Most of the times, patients changed their camera arrangement to communicate the required information to the clinician. For instance, in session 8 (video), when Camilla was showing the shoulder and hand exercises by lying down on her bed, Phil wanted to check the range of her hands and shoulder movements. However, he could not get that information as Camilla's laptop (camera) was kept away from the bed. Later in the session, Phil asked Camilla to demonstrate another set of hand movements, while sitting on the chair. This time Phil guided Camilla about how to position the camera so that he could get a good view of her hand movements. Following the instructions, Camilla sat sideways on the chair and Phil could then see the range of and smoothness in her hand movements, and facial expressions (e.g., eyes closed and stressed).

On the other hand, checking Laura's improvement in her ankle was not easy for Phil to check over video. Since her exercises were related to ankles, checking the subtle differences required the camera to be more focused on her ankles. Additionally, at some times, Phil also wanted to check her full-body posture and weight distribution with different exercises. However, he could not observe that fine-grained information related to her movements over video. Consequently, Phil decided not to organize video consultations for her, and rather meet face-to-face.

Phase 3 & 4: Examination and Diagnosis

In this phase, the essential bodily cues are tactile characteristics, response to touch, touch and body movements.

C6: Hands-on Examination is Not Possible

During face-to-face consultations, clinicians performed physical examination of the patients by pressing, touching and feeling different body parts. For instance, in session 2 (face-to-face), Phil performed Anna's examination, while she was lying on the plinth. Phil pressed the area around her stomach and ribs to figure out the location of pain. While he was pressing, Anna kept her hands near her rib to respond to any touch that could create more pain (protective spasm). Phil inquired about the pain intensity as he continued on pressing. Since Anna had inflammation near her ribs, Phil asked her to feel his ribs first and then describe him how it feels different in her body. In this way, both Phil and Anna touched each other ribs to gain good understanding of Anna's health. Physical examination, therefore, not only provided tactile feedback related to the feel (tightness) of her tissue, body inflammation, and skin temperature but also provided information related to her emotional state.

As one can imagine, conducting hands-on examination was not possible over video. However, clinicians tried to conduct the oral examination whenever required in the video consultations. For instance, in session 1 (video), Pain consultant asked different questions from Anna, *"Is it sensitive to touch on your body?", "Is your t-shirt tolerable?"* Anna replied to these questions and described verbally about her health condition. Later, Phil also orally examined the pain points of Anna through different ways. In this regard, he adjusted his t-shirt to show his ribs to Anna over video and asked her to follow him from top of her t-shirt. Following Phil, Anna pressed the area around her ribs and told him the pain points. Additionally, Phil also inquired pain location associated with different movements such as bending his neck sideways, twisting to one side and breathing patterns. Anna repeated these movements and described pain points. Although Anna followed what Phil suggested but she was afraid to touch her body because of the extreme pain. Consequently, Phil could not get sufficient information of Anna's issue, and therefore, he scheduled the next consultation as face-to-face.

C7: Environmental Probes are Out-of-View

During face-to-face consultations, clinicians sometimes examined the patient's health issue by asking them to do certain tasks in the immediate environment. They interleaved such tasks within their conversation such that patient did not realize them as specific tasks. The intention behind these tasks was to check the spontaneous reaction of the patient without giving much time to them to ponder and alter their body movements. For instance, in session 3 (face-to-face), Phil wanted to check Anna's decision making power as she was shortly resuming her schooling. Phil asked Anna to stand up on the plinth in the flow of their conversation. Anna thought for a while and then did not do it. Phil was happy on Anna's decision, as it could have hurt her knees. Since Phil was available in the room, it was easy for him to stop Anna if she were to try it.

During video consultations, clinicians did not have any information related to the patient's immediate surroundings. The webcam at both ends was mainly focused on the face and covered the upper torso of the participants. Such an arrangement although supported eye contact between clinician and patient, but restrained the clinicians in examining unconscious actions of the patient with different artifacts in the surrounding.

Phase 5: Treatment

In this phase, the essential cues for clinicians are body postures, hand gestures, touch, tone of speech, body movements and facial expressions.

C8: Limited Scope to Recommend New Exercises

During face-to-face consultations, clinicians suggested new exercises to patients after seeing their progress. These exercises sometimes were completely different from what patients were already following, while at other times, they were slightly modified. The important aspect of the exercises was to follow the correct body posture so as to gain the necessary outcome. In this regard, clinicians first demonstrated the new exercise to the patient and then asked the patient to perform it together. For instance, in session 7 (face-to-face), Phil demonstrated a new exercise to Laura where he crossed his legs, and bent down to touch the floor with his hands. As Laura was following Phil, he guided her how to maintain the correct posture. He also laid emphasis on the correct posture by touching her back and using hand gestures to describe the body parts that will be under stress during the exercise. Additionally, clinicians paid attention to patient's fatigue and facial expressions to check their capability of doing the recommended exercise. Sometimes, after showing all new exercises, clinicians also made another physical examination to check if the exercises had caused any inflammation or had alleviated her pain.

During video consultations, clinicians never suggested a completely new exercise to the patient as they were unsure of getting a good understanding of the patient's postures over video. To this end, the clinicians limited the treatment only to slightly tweaking the already suggested exercises. Although clinicians always wanted to explain the exercises along with a short demonstration, however, the technical issues related to video and audio quality sometimes enforced them to describe the exercises orally. For instance, in session 8 (video), after reviewing Camilla's progress, Phil wanted to show her a new exercise of standing push-ups against wall. However, Camilla reported that Phil's video on her side was blurred. As a result, Phil verbally described the exercise and stressed on the required body posture through hand gesture. Using hand as an emblem, he repeated the posture twice in a low pitch. Camilla was familiar with the exercise and thus grasped it very quickly. Phil still wanted to check her posture, therefore, asked her to show it by standing against the wall. The bad video quality further restricted him to see her complete posture. And at the end, he had to verbally confirm that Camilla was following the posture correctly.

Phase 6: Ending

In this phase, clinicians checked patient's facial expressions and body language to understand their emotional state.

C9: No Room to Accommodate After Thoughts

To schedule the next appointment during face-to-face consultations, clinicians opened up their calendar and shared the desktop screen with the patient (and caregiver) to find a suitable date. While discussing the possible dates, patients and caregivers talked about their plans that sometimes opened up new topics for immediate discussion. For instance, during session 3 (face-to-face), Anna talked about the school trip in which she was very much interested to go. Phil got bit worried on how would she handle her pain during the trip. They then discussed the strategies and made a plan for the trip. Additionally, there were opportunities for patients to bring after-thoughts of the consultation, while leaving the room. Clinicians also introduced small talk related to their journey back home and other school activities, as they walked out together. While patients were leaving the room, clinicians looked for the patients' facial expressions and body language to understand their emotional state after the consultation. Phil described that when patients are happy with the consultation, they walk and talk more confidently and smile more as they leave the consultation room.

Ending of a video consultation was very short and direct. Clinicians could not observe patient's body language as everyone continued sitting in front of the camera and then they directly disconnected the call. Additionally, since there was no shared calendar, both ends checked their personal calendar to schedule the next appointment. Such scheduling not only took clinician's attention away from the patient but also did not allow any new topic to surface up. Finally, in the absence of any opportunistic conversations, clinicians vocally confirmed if the patient had any other concerns to discuss.

DISCUSSION

Our study illustrated that clinicians rely on a wide range of bodily information across different phases of a consultation. These cues are naturally available for clinicians during face-to-face consultations, however, a wide-range of bodily cues were not present during video consultations. Table 3 summarizes the challenges faced by clinicians during video consultations. Some of these cues got missed because of the different structure that video consultations follow. For instance, the incidental cues related to walking and talking style of the patient were missed (C1), as the video consultation started and ended with patients sitting in front of the camera. On the other hand, some bodily cues were not available during video consultations because of the limitation of video technology. For instance, subtle differences in the exercises such as depth of squats, and range of movements were not distinguishable over video (C5). Similarly, tactile information related to patient's body and their response to touch was missed because of the limitation of video technology in supporting hands-on examination (C6).

There were instances when the limited access to bodily cues over video posed severe challenges to clinicians in appropriately assessing the patient's health condition. In such scenarios, clinicians scheduled next appointment as face-to-face so that they can conduct the necessary examination. For instance, when Phil did not get a complete understanding of Anna's health over video, he called her for a face-to-face consultation. Additionally, video consultation did not prove beneficial for patients like Laura who were shy in elaborating their symptoms and where the improvement was not noticeable over video (C3). In this regard, factors like visibility of health issue over video and patient's ability in narrating their experience influenced the success of a video consultation. As such, clinicians mainly used video consultations to organize follow-up consultations for patients with whom they have already established a good rapport after a couple of face-to-face consultations. Moreover, they often switched from video to face-to-face consultations to perform timely examination as well as to recommend required treatment (new exercises). To this end, video consultations were not treated as the replacement of face-to-face consultations, but rather they were organized in adjunct to face-to-face consultations.

In the current practices of video consultations, technology carries a strong voice where participants arranged their interactions to address the technological limitations in supporting bodily communication. In the lack of bodily cues, clinicians adopted new practices to obtain the required information. For instance, clinicians introduced a show-and-tell strategy where they demonstrated different activities by referring to their body, while patients followed the actions and described the required information. Similarly, patients changed their orientation depending upon the arrangement and capability of the underlying technology. The dominance of technology in clinical consultations has also raised concerns of depersonalizing clinician-patient relationship [30] and drowning out the voice of patients with technology [40]. Future technologies for video consultations should therefore be designed to support the essential bodily communication so that the relationship between clinician and patient can be nurtured.

Phases	Challenges encountered during video consultations
Opening	C1: Limited availability of incidental cues C2: Limited opportunities for small talk
History Taking	C3: Elaborating symptoms require vocal expertise C4: Performing certain exercises feel awkward C5: Subtle differences in the exercises are difficult to observe
Examination & Diagnosis	C6: Hands-on examination is not possible C7: Environmental probes are out-of-view
Treatment	C8: Limited scope to recommend new exercises
Ending	C9: No room to accommodate after thoughts

Table 3: Challenges encountered during video consultations.

DESIGN SENSITIVITIES

To inform the work of researchers and designers creating applications for video consultations, we articulate our understanding of bodily communication as four *design sensitivities*. Design sensitivity guides designers to consider key relevant areas, while designing technologies for the given context [9]. Design sensitivity does not prescribe any strict guidelines or solutions, but rather inspire creative design thinking by defining areas for discussion.

Visual Acuity

Visual acuity is the ability of eye to visually discriminate between different forms [10]. In the context of physiotherapy, visual acuity is related to the clinician's ability to discern subtle changes in the exercises of a patient, e.g., depth of squats, range of arm movement, point of balance, and weight distribution [4,28]. We found that during video consultations, clinicians could not observe the subtle differences in the exercises of the patients (C5), which were easily accessible in face-to-face consultations. Gaver [17] explained the reason behind the limited visual acuity of video systems. He described that the level of details on video is always fixed at pixel size. And since video communicates high-frequency 3D information in one frame, even the sharpest pixel will only provide the structure but not the real details of the scene.

Instead of improving the visual quality of the video technology, we suggest to augment video consultations beyond visual acuity. In this regard, squeezable interfaces [44] and wearable technologies [48] have the potential to capture fine-details of the patient's movements such as weight distribution and range of movements. Additionally, Microsoft Kinect based systems [47] and Vicon Tracking system e.g., [41] could also be utilized to get orientation and posture related information of the patient. Since these technologies provide information in abstract visualization, patient's privacy can also be maintained.

Field-of-view

Field-of-view is the extent of a physical space that can be seen at a given time. In our study, we found that clinicians were restricted by the single view of the patient's space. For instance, since the webcam remained focused on the upper torso, clinicians could not see the patient's body language during conversation. The single and constrained view also limited their access to patient's environmental probes, which they typically utilize to perform covert examination (C7). Having a single field-of-view also limited their understanding of the patient's body movements; consequently they refrained to suggest new exercises over video (C8).

We believe that video consultations will greatly benefit by expanding the spatial information of the patient end. One plausible solution is to make the video call on a bigger screen with a wide-angle webcam. Additionally, field-of-view can also be widened by installing multiple cameras at the patient's end, as illustrated by [18,26,39]. However, to address the issue of patient's discomfort discussed earlier, the data captured from multiple cameras need not be presented as video to the clinicians. Rather it could be abstract visualizations such as graphs of angular movements, as explored by Tang et al. [41]. As such, the visualization should offer quick facts to the clinicians regarding the patient's body movements so that they can continue with the main purpose of the consultation.

Clinical Asymmetries

Our findings speak to two types of asymmetries described in the literature: 1) *Institutional asymmetry* [42] defines the asymmetry in the roles and responsibilities during the clinical consultations where clinicians leverage higher authority than patients. 2) *Communicative asymmetry* [23] describes the varied use of the communication resources to support co-participation. In the context of video consultations, we found that these asymmetries were intertwined where the authority held by the clinicians guided patient's interactions with technology. For example, during video consultations, clinicians requested the patients to reposition the camera to clearly see the patient's movements and other activities. Patients, on the other hand, followed the instructions but hesitated to make such requests when clinicians demonstrated new exercises.

We found that video technology further magnified the responsibilities and needs of the participants by limiting a variety of bodily cues. For instance, in the beginning of a video consultation, clinicians were pre-occupied in making the technology work smoothly; thus they did not get opportunities to introduce small talk (C2). While clinicians struggled to get complete information of the patient's bodily cues, patients struggled in getting higher mobility with the underlying technology. These attempts also raised concerns at the patient end where they felt uncomfortable in performing certain types of exercises over video (C4). The current systems for video consultations are not designed according to the specific needs of clinicians and patients. For instance, these systems provide the same interface to patients and clinicians and offer similar functionalities as provided by any other video platforms for non-clinical purposes. As also iterated by [2,12], we make a call to design technology that accommodates clinical asymmetries and fulfils the different needs accordingly. For example, during video consultations, clinician needs detailed information about patient's movement to support diagnosis, while patient requires comfort to capture their movements.

Time Sequence

We found that a video consultation also followed a streamlined timeline where participants occupied their seat before starting the consultation and remained seated until the end. As a result, clinicians did not get incidental cues related to patient's movements (C1) as well as their emotions after the consultation (C9). We suggest expanding video consultations in terms of time sequence such that incidental cues become available to clinicians. One potential way could be to start a video call right from the time when the patient is making arrangements for the consultation e.g., taking up their seat, placing the technology, and arranging the chairs. Similarly, the ending phase of the video consultation could be stretched a bit longer such that the clinicians can see how patients feel at the end of the session. Although this is more of a practice guideline than a technological implication, but technology needs to be designed carefully such that the extension blends well with the overall consultation.

CONCLUSION

In this paper, we presented clinician's perspective on the importance of bodily communication for physiotherapy related video consultations. Our study indicates that despite the challenges of communicating bodily cues during video consultations, clinicians find video consultations beneficial, particularly for follow-up consultations as it save patients trips to the hospital and their disruptions to schooling. We reflected on our findings as four design sensitivities, which speak to designing video technology beyond visual acuity, expanding the field-of-view, accommodating asymmetries of the clinical setting, and extending the temporality of video consultations. Although we studied people with chronic pain undergoing physiotherapy, the proposed sensitivities could also be helpful in other domains that rely on bodily communication e.g., rehabilitation. Further research is required to study if video consultations for other clinical domains also progresses through 6 phases; and to investigate if the importance of bodily communication is similarly acute with conditions that do not involve pain.

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E.3. Conference on Human Factors in Computing Systems (CHI 2017)

This document presents the full paper published in the ACM Conference on Human Factors in Computing Systems, CHI 2017. This publication resulted from the findings of Study 2 and also includes a brief account of the development of *SoPhy*. The paper was presented at the conference. The full citation of the paper is:

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SoPhy: A Wearable Technology for Lower Limb Assessment in Video Consultations of Physiotherapy

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ABSTRACT
Physiotherapists are increasingly using video conferencing tools for their teleconsultations. Yet, the assessment of subtle differences in body movements remains a challenge. To support lower limb assessment in video consultations, we present *SoPhy*, a wearable technology consisting of a pair of socks with embedded sensors for patients to wear; and a web interface that displays information about range of weight distribution, foot movement, and foot orientation for physiotherapists in real-time. We conducted a laboratory study of 40 video consultations, in which postgraduate physiotherapy students assessed lower limb function. We compare assessment with and without *SoPhy*. Findings show that *SoPhy* increased the confidence in assessing squats exercise and fewer repetitions were required to assess patients when using *SoPhy*. We discuss the significance of *SoPhy* to address the challenges of assessing bodily information over video, and present considerations for its integration with clinical practices and tools.

Author Keywords
Video communication; clinical consultation; physiotherapy; bodily communication; wearable technology.

ACM Classification Keywords
H.4.3 Communications Applications: Computer conferencing, teleconferencing, and videoconferencing.

INTRODUCTION
Physiotherapists are increasingly using video conferencing tools to conduct consultations over-a-distance [13,14,30,40]. Yet, despite the benefits of transcending long distances, video consultations limit access to bodily cues and reduce clinician's confidence in accurately assessing the patient. Consequently, the treatment offered by physiotherapists over video is less specific than that given in face-to-face consultations [3].

Lower limb movements are particularly, difficult to assess over video because video conferencing tools are typically configured to support talking heads conversations. Video conferencing tools have little consideration for the observation of full body movements [22]. Physiotherapists find it difficult to assess lower limb movements such as weight distribution, fatigue, and details on exercises that involve multiple joint movements (e.g., squats) [3]. While computer vision techniques are explored significantly in physiotherapy [18,28], these approaches have limitations in capturing the subtleties of movements, especially related to lower body [18,39]. We, therefore, explore the potential of a wearable device to enhance video consultations.

We present a novel wearable technology, *SoPhy* that can capture lower body movements during video consultations of physiotherapy (Figure 1). *SoPhy* consists of (1) a pair of socks for the patient to wear, which contains three pressure sensors and one Inertial Measurement Unit to capture lower body movements, and (2) a web interface that visualizes information about weight distribution, range of movement and foot orientation to physiotherapist in real-time.

We conducted a laboratory evaluation to investigate how *SoPhy* helps physiotherapists in their assessment of lower limb movement. The evaluation was based on 40 simulated assessments through video consultations across two rooms in a laboratory setting. The assessments were conducted by

Figure 1: The wearable components of *SoPhy:* Each sock consists of three pressure sensors and one IMU.

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10 postgraduate physiotherapy students. Each participant performed four assessments– two each with and without *SoPhy*. The findings suggest that *SoPhy* increased the confidence of participants in assessing squats. Fewer repetitions were required for assessment when using *SoPhy*. For patients with low pain, *SoPhy* helped in comparing the subtle differences in feet movements, while for extreme pain conditions, *SoPhy* served as a training tool.

This paper makes the following contributions: First, we developed *SoPhy*, a novel system to extend video consultations with precise information about body movement. Second, we contribute a study of our system, which highlights the utility of visual feedback to help assess lower body movements. Finally, we identify a set of challenges and design considerations to integrate this feedback with clinical practices and tools.

RELATED WORK

Video Consultations

Over the last decade, video consultation has emerged as a recognized practice to offer diagnostic and therapeutic advice to patients who otherwise, have limited access to health service [13,14,30,40]. Clinicians and patients utilize video conferencing tools, like Skype, for the purpose of communication. Video consultations are used in a variety of clinical domains, such as surgery [35], physiotherapy [3], autism education [4], and knee rehabilitation [30].

As yet, video consultation systems predominantly utilize audio and video to support communication with different setups like multiple screens [35] and interactive walls [25]. Recent study [3], however, challenged the applicability of audio-video media for physiotherapy consultations. This study demonstrated that physiotherapists either miss the crucial bodily cues altogether or do not get sufficient details about body movements because of the limited visual acuity offered by video technology. The absence of the essential information reduced clinician's confidence in suggesting new exercises to patients, and they were limited to tweaking previously recommended exercises in video consultations.

Previous works have emphasized the need to communicate essential bodily cues to the clinicians, the absence of which influences the treatment outcome and clinician-patient relationship [9,36]. The lack of clinician's confidence may reduce patient's trust on the clinician and adherence to the treatment [36]. Furthermore, Lee et al. [21] expressed the fear of dehumanizing clinician-patient relationship with limited ability of clinicians in making decisions over video. While there is evidence that video technology does not support all the essential information that clinicians require [3,11,26], lesser attention is paid to explore technologies that could support clinicians in their assessment. Below we discuss the existing technologies that could potentially support physiotherapy related video consultations. However, these technologies have certain limitations, which motivated us to design a novel wearable technology, *SoPhy*.

Technology for Rehabilitation

There is a growing interest in body tracking technologies to support rehabilitation [28]. This is typically undertaken with automated pose detection and estimation techniques using computer vision approaches. Technologies like Microsoft Xbox Kinect [18] and Vicon motion tracking cameras [37] are used to guide patients to complete their rehabilitative routines without the supervision of physiotherapists. Along the similar vein, Hoang et al. [17] explored the opportunities with virtual reality environment to guide students on body postures for remote sessions. However, these technologies have limitations in capturing the fine-grained movements, such as range of joint movements and body orientation [18,39]. Details about these fine-grained movements are particularly relevant to accurately assess the biomechanics of lower limb.

Capturing lower limb movements in video consultations is challenging. It requires different camera orientations to accurately render depth and perspective. Also, focusing the camera on specific body parts may limit other crucial information related to patient's full body posture, and facial expressions that clinicians look for to understand patient's recovery [3]. To accurately capture lower limb movements, there have been studies [5,6,20] that utilize sensors to track and visualize knee angles during exercises. These systems present the captured information on a computer screen [6, 20] or directly on a wearable device using lighted fabric [5]. For example, BASE [12] is an ankle work sensor that is designed to improve lower limb strength and balance of elderly people. The system provides both visual and audio feedback to users for home rehabilitation.

Other related work concerns sensing socks, shoes and boards to support low-limb rehabilitation. For instance, as people with foot ulcers get little sensations in their feet, pressure sensing socks [10,27] and shoes [31] are developed to prevent them from hurting themselves. Some attempts are also made to help people in improving their postural stability (e.g., Sensoria Fitness Socks [32]), and to offer better understanding of one's own body [38]. Nintendo Wii [24] is another popular device to capture weight distribution for standing positions. However, these systems are either not commercially available or do not provide open API to adopt the software as needed. Additionally, these systems are not specifically designed to support video consultations. Therefore, the visual output is presented locally on a mobile or computer screen and not available to access remotely.

Considering the prior success of sensor-based socks in clinical settings [27], we explored the use of socks to support lower limb assessment in video consultations for physiotherapy. Also, as socks conform to the body and move along with the patient, we can accurately capture the dynamicity of a physiotherapy session where the patient performs a variety of static and dynamic exercises [3,6]. Next we discuss the developed wearable system, *SoPhy*.

SOPHY

SoPhy (pronounced as Sophie) stands for 'Socks for Physiotherapy'. *SoPhy* is a wearable technology that is designed to support lower limb assessment in physiotherapy related video consultation. *SoPhy* has two parts: first is a pair of socks containing three pressure sensors and one Inertial Measurement Unit (IMU) to capture lower limb movements (Figure 1); second is a web interface that presents information related to weight distribution, foot orientation, and range of movements to physiotherapists in real-time (Figure 2).

Patients wear the *SoPhy* socks before starting the video consultation with physiotherapist. During the video consultation, the physiotherapist asks the patient to perform lower body exercises (e.g., squats, and tip toes). As the patient performs the prescribed exercises, the socks capture data about foot movement. This data is then sent to the web interface, where the physiotherapist can see this information in real-time. We designed a mobile app to support the communication between the socks and web interface, via a Bluetooth shield [34] attached on the socks. As such, the *SoPhy* socks capture data about the *weight distribution*, *foot orientation*, and *range of movement* in the following way:

Weight Distribution: Weight distribution describes how much weight a person is bearing at different points on the sole of the foot e.g., on toes, balls, and heel. A healthy person distributes their weight equally on each foot. However, the pattern changes if the foot is injured. For example, if the big toe of a foot is injured, the person may bear more weight on the outside of the foot.

SoPhy captures the pattern of weight distribution across the balls and heel of the foot using pressure sensors sewed on the socks. Corresponding to each sensor, the weight distribution is represented by the colors and numbers shown on a sketch of the underside of the feet (refer the lower half of Figure 2). The color spectrum denotes the measure of weight on each point, while the number shows the pressure values on a scale of 0-30.

Foot Orientation: Foot orientation refers to the alignment of foot in four directions.

- *Dorsiflexion* occurs when the person bears weight on the heel of the foot.
- *Plantarflexion* occurs when the weight is on the balls and toes of the foot.
- *Medial orientation* when the weight is on the inside of the foot and the person lifts the outside of foot up in the air.
- *Lateral orientation* is when the person bears weight on the outside of the foot and lifts the inside of the foot up in the air.

Foot orientation is captured by an IMU mounted on the socks at the bridge of the foot. For the web-interface, we used ten sketches to display the foot orientation: three each for dorsiflexion and plantarflexion, and two each for medial and lateral orientation. These sketches change in real-time based on the captured data (refer upper half of Figure 2).

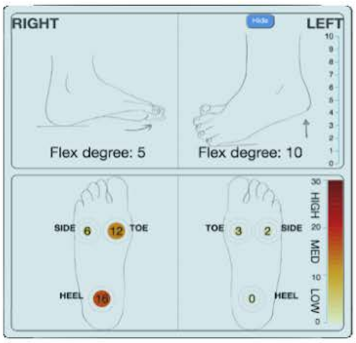

Figure 2: The *SoPhy* web-interface displays information about the weight distribution, foot orientation and range of foot movement.

Range of Movement: Range of movement refers to the magnitude of foot orientation across four directions described above. The range is defined on a scale of 1 to 10 and is calculated from the IMU data. On the web-interface, this value is represented as a 'Flex degree' under each foot.

DESIGN PROCESS

The final design of *SoPhy* was the result of multiple explorations and e-sewing trials over a 6-month period. The different phases of scoping the problem and iterating socks and web interface are described here in a linear order for clarity, but in practice they were intertwined.

Scoping the Problem and Ideation

The problem was initiated through collaboration between the University of Melbourne and the nearby Royal Children's Hospital. The physiotherapist at the hospital (author Mark Bradford) has been conducting video consultations for over three years. From our previous study [3], we identified the following lower body cues that were crucial to assess leg exercises over-a-distance: weight distribution, range of movement, depth, fatigue, smoothness of movement, and posture.

Together, we brainstormed ideas about how to best capture these cues. We explored various sensor technologies (e.g., flex sensors, accelerometers, ultrasonic band) and where to position these sensors on the body. These ideas were rendered as design sketches and discussed with the physiotherapist to assess their merit. Two bodily cues were discarded after brainstorming: posture was excluded as it can be observed over the video; and fatigue was excluded as a person can feel tired for multiple reasons not related to medical conditions. The physiotherapist affirmed that weight distribution, foot orientation, and range of movement would offer valuable insights that are not easily

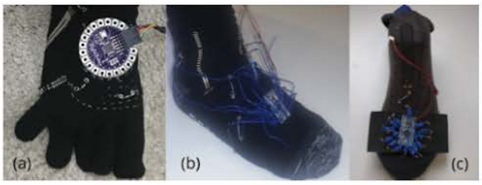

Figure 3: Early iterations of *SoPhy*: (a) Toe socks (b) normal socks with 4 flex sensors (c) normal socks with 1 flex sensor.

available over video. We also discussed the body positions for sensors, and learnt that the weight of a healthy person is predominantly distributed over the balls, heel and big toe of the foot. Hence, we chose these three locations for sensors to gauge the best understanding of weight distribution.

Ongoing discussions with the physiotherapist as well as with engineers and designers in our research center were critical in developing ideas for the design of *SoPhy*. In a second meeting with the physiotherapist, we discussed the calibration of sensors for different foot sizes, and the potential visualisation of the captured data. We asked the physiotherapist to try out the socks and comment on wearability. In the last meeting, we role-played a video consultation with a sock prototype and paper prototypes of data visualisations to evaluate their clarity and usefulness.

Iterations of the *SoPhy* Socks

We started our design process from identifying the right sensors to capture the required data. We selected Flexiforce Pressure Sensor [15] for capturing weight bearing on the foot. Initially we aimed to capture pressure values on each toe to give us rich data about weight distribution (Figure 3a). However, given the small surface area of toes, sewing pressure sensors on toes and avoiding short-circuiting of connections around LilyPad were challenging. Hence, we reduced the number of sensors to three: one on each ball and one on the heel. Reduction of pressure sensors then affected our choice of socks and we then used the regular socks (see Figure 1 for the final design).

Capturing range of movements however, required multiple iterations, as there are different sensors available for this task. In the beginning, we explored the use of flex sensors [16] because of the ease to process the captured data. We tested flex sensors by sewing four of them on socks around the ankle (Figure 3b). However, owing to the limited movement around ankle, the flex sensor was not sensitive enough to capture the movements. Finally we opted for the Adafruit 9-DOF Absolute Orientation IMU Fusion Breakout [1]. IMU provides data points across xyz coordinates, which we processed to derive values of foot orientations and range of movement.

We tried two microcontrollers: LilyPad [23] and Arduino ProMini [2] to capture the data from the sensor. We opted for Arduino ProMini, as it is smaller in size, therefore, easy to accommodate on the socks; and it has more analog pins

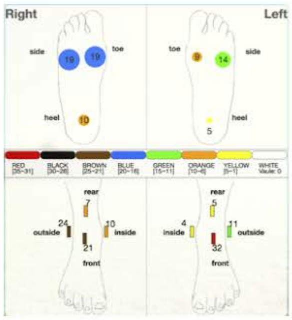

Figure 4: Previous interface with flex sensors visualisation.

to wire in sensors. However, it raised issues of short-circuiting as all the pins were very close to each other. To avoid short-circuiting issues, we used thin conductive wires to make connections (Figure 3b, 3c). However, exposing wires on socks made it look less wearable. Hence, in the final design we covered all connections to Arduino underneath several layers of clothes (see Figure 1).

Iterations of the *SoPhy* Web-interface

For the web interface, we explored different ways to present the sensor data. We initially considered using photos of the underside and the side of the foot to provide a realistic visualisation. However, we chose sketches instead to simplify the visualisation and to make them neutral for age and gender. Being smaller in size, using sketches also improved the latency of updating the web-interface in real-time based on the sensor data. We also switched from using foot sketches of the front view (Figure 4) to side view (Figure 2). Because side view provides a different perspective of the patient's feet to clinicians as opposed to the front view, which is already available in a typical video call. The other change for the web-interface was the use of a color spectrum to maintain visual consistency. The final design of the web interface is shown in Figure 2.

EVALUATING SOPHY

We conducted a laboratory study to investigate how *SoPhy* helps physiotherapists in conducting lower limb assessment during video consultations. Taking inspiration from prior works [21,35], we simulated video consultation settings to evaluate *SoPhy,* but aimed to mimic the structure of video consultations as closely as possible. To this end, we organized the consultation across two rooms in the lab. We used Skype to arrange video conferencing, as it is one of the standard tools at the collaborating hospital. The study was approved by the university ethics committee.

Participants

We recruited participants to play two types of role: 1) the physiotherapist and 2) the patient. Participants were recruited from the university's mailing list.

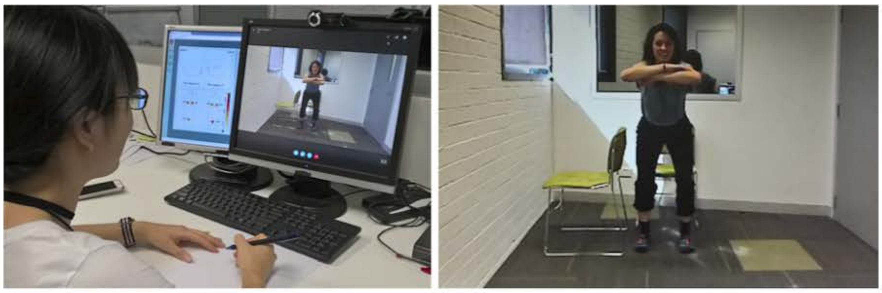

Figure 5: Study setup- In left, a participant using *SoPhy* interface during a video session. On right side: the actor is performing squats wearing *SoPhy* socks.

For the physiotherapist role, we recruited 10 students (3 male, age range: 23-28 years) from the second and final year of the postgraduate physiotherapy degree at our university. For this role, participants were expected to have completed formal training on standard patient assessment and treatment relating to different issues in their study. As part of the degree program, participants had prior experience in role-playing different patient profiles to learn assessment and treatment. They had completed 37 weeks of clinical practice at hospitals where they assisted physiotherapists in treating patients. We utilized their skills to evaluate the utility of *SoPhy* as asking them to play the role of physiotherapists in the evaluation. No participant had prior experience with video consultation or wearable technology. The participants received a $20 gift voucher.

For the patient role, we hired a final year physiotherapy student (female, 28 years old) to play the role of patient for the entire study to get consistency (in line with the earlier study [17]). We refer to the patient as actor to avoid any confusion with our participants. We appointed her as our candidate because of her prior experience in assisting physiotherapy sessions as well as her consistency in performing the exercises for different patient profiles. We conducted training sessions with the actor to train her for different patient profiles. The actor was paid $25 per session for her participation in the study.

Study Design

The study had four conditions involving video consultations "*with SoPhy*" as the test condition, and standard video consultations "*without SoPhy*" as the baseline condition. The actor and the participants were located in two different rooms. In both conditions, communication was conducted through a Skype video call. In the *with SoPhy* condition, in addition to the Skype screen, participants were presented with the visualisation interface of *SoPhy*. Figure 5 provides the details of the study setup.

Independent Variables

The independent variables were the *consultation technology* (*with SoPhy* and *without SoPhy)* and *pain levels* (*extreme pain* and *low pain)*. Based on these independent variables, we designed a 2x2 within subject study with four conditions: *with SoPhy-extreme pain*, *with SoPhy-low pain*, *without SoPhy-extreme pain* and *without SoPhy-low pain*.

Dependent Variables

For each consultation, we asked the participants to evaluate six exercises. For each exercise, participants filled out a Patient Assessment Form with the following factors: *weight distribution, foot alignment, range of movement,* and *confidence.* We also counted exercise repetitions from the video recordings. These factors are the dependent variables of the study.

Tasks Performed by the Participants

Each participant was asked to conduct four consultations: two each with and without *SoPhy*. We randomized the order of these sessions to avoid any learning effect. Also, we created different patient profiles to makes these sessions realistic, which we discuss later. In all four sessions, participants requested the patient to perform six exercises and filled out the Patient Assessment Form (discussed in next section). After four sessions, we interviewed the participants to understand their overall experience with *SoPhy*. Participants took around 2 hours to finish the study.

Tasks Performed by the Actor

The actor was instructed to perform the following six exercises based on the patient profile: dorsiflexion, plantar flexion, double leg squats, double leg heel raises, single leg heel raises, and walking. Dorsiflexion and plantar flexion were performed while seated, and rest exercises were performed in standing. Figure 6 shows a snapshot of these exercises. We selected these exercises after consulting with a physiotherapist (last author) to ensure that the exercises represent the clinical practice, and that they were are not physically demanding for the actor to perform repeatedly.

Patient Profiles

Because each participant conducted four consultations, we created four separate patient profiles such that they find every patient as unique, without any learning effect.

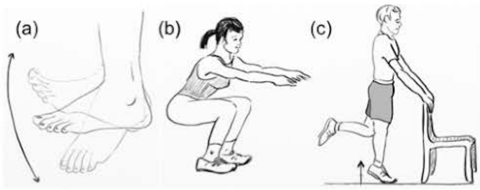

Figure 6: Description of exercises: (a) Dorsiflexion and Plantarflexion, (b) Squats (c) Single leg heel raises.

The patient profiles were created around two pain levels: extreme pain and low pain, which were created in consultation with the last author. We limited the profiles to extreme and low pain to study the utility of *SoPhy* in assessing contrasting movements, while keeping the study design simple. These extreme opposites also made it easier for the actor to consistently perform the respective roles.

Table 1 illustrates the names for each profile where Sam and Veena had similar injury in left foot, while Susan and Vicky had similar injury in right foot. The order in which each participant sees the patient profiles was randomized.

Participants were provided with the background details of each patient that described the cause of injury and how it has changed over the period of time; whereas the details of the pain and other socio-emotional factors that define movements were only provided to the patient. Table 2 shows details of the two patient profiles for extreme pain. For these profiles, we presented the following information to the actor: asymmetric walking with less weight on heel of the left foot, fearful of walking and touching, constant pain, swelling in ankle and outside of left foot, extreme pain today with pain level 5 (on a scale of 0 to 6).

For all patient profiles, video sessions were described as follow-up of face-to-face consultations. Also, all patients were described as already following on the six exercises from the last consultation along with the number of repetitions - five for extreme pain and ten for low pain. Therefore, participants did not have to explain these exercises to the patient in these sessions.

Data Collection

Since the aim of this project is to support the work of physiotherapists in video consultations, we mainly collected data from our participants. We also discussed with the actor about her experience with *SoPhy*. Following on the existing works on physiotherapy [33,37], we employed a mixed method approach where we collected from four sources. Firstly, we video-recorded the sessions and we observed participants to understand their interactions with *SoPhy*. Being present with the participants allowed us to reflect upon the latest event in a think-aloud manner. Participants also filled the Patient Assessment form during each session, which we discuss below. Finally, we conducted a semi-structured interview with participants to understand their overall experience with *SoPhy*. All interviews were audio-recorded and field notes were written for later analysis.

Pain Profiles	*with SoPhy*	*without SoPhy*
Extreme pain	Sam	Veena
Low pain	Susan	Vicky

Table 1: We created four patient profiles: two each for with and without *SoPhy* based on two pain levels.

Sam is a 16-year-old girl who works as a helping hand in a restaurant. Last year, she twisted her left foot during a busy day at the restaurant. After the incident, Sam feels pain around ankle. The pain is not constant, but on days when she has it, it gets unbearable. She has consulted many clinicians as yet, but the pain does not seem to go away.
Veena is a 15-year-old high school girl who was very active in sports until 2 years back when she twisted her left foot ankle. She has been on pain medication for 4 months and has consulted psychiatrist and surgeon. She has recently started physiotherapy to get rid of her pain. She is diagnosed with chronic pain in left foot ankle.

Table 2: Details of the two patient profiles for extreme pain.

Patient Assessment Form

We designed a Patient Assessment Form for data collection, modeled after the assessment form of the collaborating hospital and changed it as per the study goals by consulting the last author. Each participant filled one form in each session (four in total).

The form provided background information of the patient (as shown in Table 2), and required the participant to fill in the patient's pain intensity on both feet (on a scale of 0 to 6). The participant had to inquire the patient about their pain in order to fill this information, which provided a starting point for them to initiate the consultation process.

For each exercise, participants were asked to fill in the following information for each foot: weight distribution, foot alignment, range of movement, and confidence in assessment. For each factor, the participant marked a selection on a scale of 0 to 6. We provided labels for value 0, 3 and 6 for coded data. For weight distribution, participants assessed the pattern of weight distribution over each foot (labels: heel, middle, and balls). Similarly, participants assessed the foot orientation (labels: medially, balanced and laterally) and range of movement (labels: none, partial and complete) over each foot. Confidence assessment was a self-rated value with labels: lowest, medium, and highest.

The final section was dedicated to write notes about the body posture of the patient and a rating of confidence value with the overall assessment.

Data Analysis

We performed thematic analysis [7] on the field notes and interview transcripts. We coded the data on paper and created memos to capture ideas and trends emerging from the data about the interactions with *SoPhy*. We manually analyzed the video recordings to calculate the number of repetitions of each exercise.

We performed nonparametric factorial ANOVA analysis using the Aligned Rank Transform tool in R [42] on the factors *consultation technology* and *pain level*, and the interaction effect of *consultation technology**pain level* on the dependent variables: *weight distribution, foot alignment, range of movement, confidence assessment,* and *exercise repetition*. The analysis helps us to determine if the usage of *SoPhy* would affect the decision making process of physiotherapists. Using affinity diagrams, we structured key findings into five themes that we discuss next.

FINDINGS

Below we discuss the findings across five themes. We have used participant IDs (P1, P2 ...) to denote their quotations.

Increased Confidence in Assessment

The findings show that participants were more confident in their assessment when using video consultation *with SoPhy* and *without SoPhy*. For squats, there was a main effect of consultation technology on confidence ratings ($F(1,36)=10.97$, $p<.01$). *SoPhy* increased the confidence of participants in assessing squats (M=5.75, SD=1.06), as compared to the video consultations *without SoPhy* (M=4.17, SD =1.13).

The qualitative data showed that *SoPhy* was critical to confirm initial observations made through the video data. All participants developed a strategy to observe the required information from both video stream and *SoPhy* interface. They formulated an initial assessment by first observing a couple of repetitions from the video stream and then utilized the *SoPhy* interface to verify their hypothesis: "*The sock system was more like a confirmation for me. I used the strategy of first seeing the video and then form an assessment. After a couple of repetitions with video, I used the interface to confirm my assessment.*" (P8).

SoPhy reduced the need for verbal confirmation with patients and the ambiguity created by such dialogues. While participants sought verbal confirmation for their assessment in the consultation *without SoPhy*, e.g., "*It seems like you are not putting more weight on the outside of your left foot"* (P2), there were no such verbal confirmations *with SoPhy*.

Participants described that they felt more confident in their assessment with *SoPhy*. This removed the need for verbal confirmation and potential ambiguity it may bring, as discussed by participant 2: "*I did get more confident in my assessment with the socks data. Without it, I may not be able to pick up things just from video. Like I thought, 'Oh that foot looks tilted outside', but then whether it has any relation with their weight distribution or not, I can't tell just from the video. Confirming with the patient is not very helpful as they might not know what's going on with them.*"

Fewer Exercise Repetitions Required to Assess Patients

The participants reported that with *SoPhy* they needed fewer repetitions of exercises to assess patients compared with the standard video consultation. The analysis of the video recordings showed that *SoPhy* required 30-40% fewer exercise repetitions than the *without SoPhy* condition as shown in Table 3.

Exercises	*With SoPhy*	*Without SoPhy*
Dorsiflexion $F(1,36) = 6.99$, $p<.05$	M=8.10, SD=3.21	M=11.25, SD=4.54
Plantarflexion $F(1,36) = 6.14$, $p<.05$	M=7.45, SD=3.88	M=10.60, SD=4.24
Squats $F(1,36) = 8.36$, $p<.01$	M=6.05, SD=2.48	M=8.05, SD=3.18

Table 3: *SoPhy* required fewer repetitions for assessment.

One reason for the reduced number of repetitions was the increase in confidence in patient assessment with *SoPhy*. In the interviews, participants felt more confident in their assessment after only a few repetitions when using *SoPhy*. "*With sock system, I realized I got good information quite early, which was really good. I did not push her way too much then, which is what I will do with real patients. Therefore, I was more confident then.*" (P3)

A second reason was that *SoPhy* alleviated the need to ask patients to perform exercises with different camera angles. Rather than asking patients to reposition the camera to see specific body movements, *SoPhy* offered rich information equivalent to multiple camera view points: "*Over video, I can't see what's going on behind the foot, especially for exercises like plantarflexion. I can see the person only from one direction. The system provides me this detailed information irrespective of how the person is standing or sitting. Of course you can ask the person to turn around, but unless you are right there you would not understand what is going on. I did not ask the patient to turn backwards or sideways when I had the sock data. The system was already doing it for me.*" (P3)

Reducing the number of repetitions is important especially, for patients in extreme pain, as it helps clinicians to avoid movements that could inflict further pain to the patient. "*If a person is in extreme pain, I wouldn't ask them to do more exercise. I wouldn't want them to keep going otherwise, they will lose trust in the therapy.*" (P3)

Weight Distribution Offers Hitherto Unavailable Insights

Weight distribution was the most useful information provided by *SoPhy*, i.e., because it provided hitherto unavailable information for participants. Range of motion and orientation presented by *SoPhy* offered a more detailed understanding of these issues and increased confidence in assessment, but these measures were largely inferred from the video alone. Unlike range and orientation data, there is no direct way to observe weight distribution. Participants reported that in face-to-face assessments, they rely on indirect clues to understand weight distribution, e.g., *"from the noise they are making while walking"* (P5). However, such clues vary based on different factors (e.g., shoe sole, and weight bearing) and are difficult to observe over video.

Hence, the weight information provided by *SoPhy* offered a novel, direct way to assess patients. The visualisation not only helped them to understand which foot is bearing more weight, but also how weight is distributed across each foot. "*It's always challenging to understand weight bearing because the pressure points are not visible. The socks data certainly helped in that way. It's easy in cases when the person is putting more weight on one foot than other. But it is difficult to understand how the pressure is distributed across the foot, is it on the heels, or on the balls.*" (P8)

The information of weight distribution also offered insights into the lateral and medial orientation of foot, which are difficult to observe. One participant described the difficulty that she faced in checking the foot orientation in sessions with standard video consultation: *"When I asked the patient to turn sideways to see the lateral and medial alignment of the foot, the front leg obstructs the other leg. It's harder to see both legs at the same time from here."* (P7)

Another participant described how *SoPhy* helped him to understand these orientations: "*The values of weight distribution were sufficient for me to know that the person is moving laterally or medially. The numbers tell me that the person has pressure on the outside, inside or at the back. So then visually I can get that if the pressure is on the outside, meaning she is going laterally.*" (P10)

The statistical analysis further underlined the difficulty of assessing weight distribution and the difference that *SoPhy* makes here. The analysis showed that there is a significant difference in assessing the lateral and medial alignment of the affected foot between *with SoPhy* and *without SoPhy* conditions: dorsiflexion ($F(1,36)=4.30$, $p<.05$), double leg heel raises ($F(1,36)=7.63$, $p<.01$) and single leg heel raises ($F(1,36)=25.50$, $p<.001$).

The interaction effect between *consultation technology* and *pain level* was significant for the medial and lateral alignment factor for dorsiflexion ($F(1,36)=4.30$, $p<.05$) and squats ($F(1,36)=12.70$, $p<.01$). We then performed two Wilcoxon signed-rank tests using Bonferroni adjusted alpha level of 0.025 per test (.05/2), to analyze the effect of *SoPhy* within each pain level for dorsiflexion and squats. For squats, there was a main effect of *SoPhy* on assessing the alignment in *extreme pain* condition, ($Z=3.92$, $p<.025$). There was no other significant pairwise comparison found.

It is important to note that the results do not indicate the assessment being more accurate, as there is no benchmark to make this comparison. However, the difference in the assessment highlights that *SoPhy* did not merely confirm assessments made via video, but that it also helped in assessing weight distribution for different foot orientations.

Pain Levels Influenced Assessment with *SoPhy*

The level of pain experienced by patients is an important factor for physiotherapists because it affects their choice of exercises and repetitions to recommend to patient. We found that the pain level had significant effects on alignment assessment throughout all exercises: dorsiflexion ($F(1,36)=27.70$, $p<.001$), plantarflexion ($F(1,36)=29.90$, $p<.001$), squats ($F(1,36)=9.75$, $p<.01$), double leg heel raises ($F(1,36)=30.06$, $p<.001$) and single leg heel raises ($F(1,36)=20.06$, $p<.001$).

Participants stated that they used *SoPhy* differently depending on the pain condition. In extreme pain, participants focused more on training and motivating the patient to perform movements, where *SoPhy* could be used as a feedback for patients: "*In extreme pain, the system might be more useful for patients to see what's happening. So they could see that they are scoring 3 on that affected area whereas it's 18 on the other foot for the same location. In pain, quite a lot of sensations get mixed up and they are not able to distinguish the difference. Now through numbers, you can talk through what they are doing as opposed to what they should be doing.*" (P5)

For low pain conditions, participants described that the aim of physiotherapists is to optimize patient's movements with focus on subtleties, such that they could get back to their normal movements. Here, *SoPhy* will help in making comparisons on the patient's recovery. One participant highlighted the challenge of bringing the patient back to the normal movements and how the system would help: *"In pain, people change the biomechanics of their body to allow them to do different activities. They might have developed some secondary changes down the road. Like to walk, they kind of hit the ground and then pull the foot in some sort of fashion. It's harder to eyeball all these tricks, and you can't even confirm it with the patient. That's where the numbers [from SoPhy] will help me to see whether there is any improvement in the patterns or not."* (P10)

Challenges in Mapping Information with Observations

The findings also highlighted several challenges in interpreting the information provided by *SoPhy* with observations from the video. Several participants reported that it took them a while to learn how the system works and how to relate the information presented by *SoPhy* to the information gleaned from the video. *"It was a little bit distracting in the beginning when you don't know what to see when. I spent too much time looking at the numbers without much looking at what the patient was doing."* (P10)

The main challenge was to map the information offered by *SoPhy* with the movements visible over video stream. The visualisations offered by *SoPhy* were presented on a different screen to the video and simply looking at the visualisation did not provide sufficient information. "*When she was walking, I wanted to see her gait but I also wanted to check the numbers. But when I see the numbers on the other screen, it is difficult for me to understand what data corresponds to which movement.*" (P7)

Mapping left and right foot between video and *SoPhy* was also found confusing: "*Mapping the left and the right side is the biggest challenge like in video the right foot of the patient is my left foot. And then on the other screen [SoPhy interface], I need to do this mapping again.*" (P4)

Additionally, the presentation of the range of movement was found confusing. *SoPhy* presented a flexion degree (a number between 0-10) whereas participants measure the range as an angle (e.g., 70 degrees) from the starting point to the end point of a given movement. "*Right now the system gives me some numbers for range. I do not know what these numbers are, whether it's positive or negative like dorsi data is a positive angle for me, while the plantar angle is negative.*" (P10)

Finally, for some participants the sock was interfering with their observations from the video. While the sock helped in capturing new information, it also concealed information about the foot structure that participants could observe in the standard video consultation. "*The biggest issue with a sock is that it covers the foot and it is hard to see the foot moving. With socks, you see the foot as a plank but there are so many joints moving for one movement. Not being able to see the foot may not be an issue for all conditions, it is more important for injuries in toe as you might want to see how the toe is placed, or is it moving at all or not.*" *(P6)*

DISCUSSION

SoPhy enhanced the effectiveness of physiotherapy video-consultations through hitherto unavailable information related to lower limb movements. Firstly, participants felt more confident in their assessment when using *SoPhy* compared to standard video consultations. Increasing confidence in assessments is crucial because it impacts consecutive diagnosis and treatment of the patient [9,36]. Furthermore, lack of confidence can also negatively affect the patient's trust in their diagnosis and their adherence to the treatment [36]. Secondly, fewer repetitions were required when assessing with *SoPhy* than in standard video consultations. This is particularly, useful for patients having extreme pain, as fewer repetitions will reduce the discomfort experienced by the patient during assessment.

One of the key characteristics provided by *SoPhy* was the information about weight distribution. Physiotherapists cannot directly observe weight distribution in video consultations. Hence, seeing weight distribution not only between the feet but also across each foot provided crucial novel information. Information about foot orientation and range of movement was also considered useful, but mainly to confirm observations made through the video. Weight distribution, on the other hand, constitutes novel information offered by a wearable technology that is not available in standard video consultations, nor in any related work on technologies for physiotherapists [17,28,37].

While these results are promising, we also identified different challenges in integrating *SoPhy* with clinical practices and tools. Below we offer three design considerations to address these challenges.

Spatial Alignment between Visualisation and Video

We found that although participants appreciated the support by *SoPhy* to get more confidence on their assessment, they found it challenging to comprehend the information along with the ongoing consultation. They found it challenging to map the information of web-interface with the patient's movements, as the interface does not provide any reference point. As a result, understanding dynamic movements like walking was found challenging, as it requires checking information at both screens simultaneously. Participants also described the problem of split attention where looking at the web-interface made them feel being ignorant or rude to the patient. However, as clinicians are effectively using screens during face-to-face consultations [8], managing two screens during video consultations might not be a major issue with repeated exposure to *SoPhy*.

More research is required to present the data such that the physiotherapists can easily incorporate the visualisation as part of their assessment. One possible approach could be to overlay the information on top of the video such that the required information is presented alongside the respective body part. However, it may grab continuous attention from clinicians even at times when they want to focus only on the video stream – which may not be the case when the visualisation is presented on a separate screen as clinicians can ignore it whenever required.

Additionally, instead of presenting all the data at every time to clinicians, we can also present selective information to clinicians based on their needs. For instance, the system could only present the unexpected patterns such as sudden change (peaks or lows) in the weight distribution or range of movement. In this regard, audio and tactile feedback could offer significant potential as these media have been used in the past to effectively present the data [33,41]. Also, as clinicians refer to different bodily cues across different phases of the consultation [3], the web-interface can also be customized accordingly.

Align Visualisation with Clinical Practice

We found issues with the representation of the range of movement, as the provided information did not match with the clinical practice. Physiotherapists measure the range as angular movements of the joints using a device called, Goniometer, whereas *SoPhy* presented this information as a value between 0-10. On the other hand, the representation of weight distribution was substantially appreciated. Participants appreciated the use of different colors, numbers and the foot sketch showing the feet from underneath. Since the information related to weight distribution was new for participants, the presented information did not contradict with their prior clinical knowledge. This highlights that either the information presented by the technology should confirm with the underlying knowledge of the clinicians or it should set new defaults. The new representation may however, involve a learning curve in order for clinicians to embrace the information as part of their clinical practice.

An important aspect of a sensing technology is calibration [19]. *SoPhy* web-interface also needs to be calibrated for different patients as the weight distribution and range of movement will vary for different people. For instance, if the weight scale of 0-30 is calibrated for a person weighing 60 kilograms, it will not show the dark red color for a person weighing 40 kilograms. On the other hand, calibration can be provided to clinicians as a functionality to integrate into therapy. They can adjust the scale of range of movement, for example, as a goal that the patient should achieve in two weeks time.

Reveal Body Structure with Wearable technology

Our study also revealed some of challenges in designing the right socks for physiotherapy assessment. For example, being a wearable technology, *SoPhy* socks restricted participants' ability to visually assess the patient's foot. The loose fitting of *SoPhy* socks also concealed the foot contours and foot arch that participants wanted to observe from the video stream. This issue became more prevalent for extreme pain profiles with toe injury, where visual examination of the barefoot was critical for the assessment.

SoPhy socks need to be designed depending upon the clinical conditions. For instance, for patients with toe injuries, 5-toed socks or toeless socks might be a good design as physiotherapists can see weight bearing for each toe. Another important factor to be considered would be the type of material used for *SoPhy* socks. A body fitting socks made up of a stretch fabric like spandex could be utilized to make the foot contours visible. However, such body-fitting material may cause discomfort for certain patients e.g., those having swollen foot.

The third factor is the color of the socks. Using bright-colored socks could make the movements distinguishable even when used in different environments. And finally, the last key factor is the size of socks as one size *SoPhy* will not work for all. Accuracy of sensor readings will depend upon the fitting of the socks on feet. Hence, different size socks need to be designed for different sized foot. Designing *SoPhy* socks for different clinical conditions is increasingly becoming feasible given the advancements in smart textiles like FlexTiles [29].

LIMITATIONS AND FUTURE WORK

We report two main limitations of this work. Firstly, our study participants had no prior experience with video consultations. Thus, their responses might have some novelty effect, and the findings may differ in real world video consultations with experienced physiotherapists. Secondly, the role of patient was enacted by a healthy individual (actor). Although we significantly trained the actor to perform consistently across all study sessions, there might have been some unavoidable human errors in the movement data. Nevertheless, given the aims of this study, this participant cohort was the closest representative of our target population. The study findings have significant implications for the future video consultations systems.

The very idea behind organizing a video consultation is to support patients in situations when making a physical trip to the hospital is not feasible [11,40]. Extreme pain is one such condition where a long travel to visit the physiotherapists might worsen the patient's pain. In such condition, *SoPhy* could be used as a training tool where the clinician can guide the patient on how to start making lower limb movements. Equally, in low pain conditions when the patient has made a significant recovery, *SoPhy* could help them in optimizing their movements by providing the necessary feedback.

Furthermore, as the *SoPhy* socks afford mobility, it could provide more flexibility to clinicians and patients to try out different types of exercises during video consultations. Clinicians can further personalize the therapy program based on the home conditions of the patient, which further adds to the benefits of video consultations. *SoPhy* can support video consultations for a variety of clinical domains like sports rehabilitation, Orthopedics and Geriatric conditions. Considering the benefits of *SoPhy* particularly, in understating weight distribution, it could also have potential during face-to-face consultations where it could be used both as a training and feedback tool. Our future work thus, involves studying the use of *SoPhy* in natural video consultations for physiotherapy.

CONCLUSION

In this paper, we presented a wearable technology *SoPhy*, to enhance the ability of physiotherapists in conducting lower limb assessment in video consultations of physiotherapy. *SoPhy* provides information related to subtle differences in weight distribution, range of foot movement and foot orientation. Through a laboratory evaluation, we found that *SoPhy* increased participants' confidence in assessing the patient, particularly for squats exercise. *SoPhy* offered invaluable insights related to weight distribution that is neither available in standard video consultation nor in traditional face-to-face settings. Through *SoPhy*, we hope to encourage design thinking towards designing novel video consultations systems for physiotherapy.

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E.4. Conference on Human-Computer Interaction (INTERACT 2017)

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SoPhy: Smart Socks for Video Consultations of Physiotherapy

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ABSTRACT
While physiotherapists are increasingly organizing video consultations, assessment of lower body movements over video remains a challenge. We present a wearable technology, *SoPhy* that captures and presents information related to three key aspects of lower limb movements - range of foot movement, weight distribution and foot orientation. *SoPhy* consists of a pair of socks embedded with sensors for the patients to wear, and a web-interface that displays the captured information to physiotherapists in real-time. The objective of this demonstration is to offer first-hand experience of *SoPhy* and to create conversations around designing technologies for supporting bodily communication in video consultations.

1 Introduction

Over the last decade, physiotherapists have started using video conferencing tools to offer diagnostic and therapeutic advice to patients living in remote or rural areas [2,3]. While video consultations offer several benefits to patients and clinicians, our recent study [2] highlights the limitations of video technology in communicating the essential bodily information that physiotherapists need to formulate their assessment. The study showed that the physiotherapists found it difficult to understand the subtle differences in exercises such as depth of squats, and range of movements over video, particularly, for lower limb movements. The absence of the essential bodily information reduced clinician's confidence in assessing their patients and consequently, they offered less specific treatment over video than face-to-face consultations.

The importance of communicating rich information to clinicians is always emphasized [5], as it helps clinicians in making informed decisions and thereby, making the overall consultation effective. However, lesser attention has been paid to understand how new technologies could enhance clinician's ability to assess and treat patients during video consultations. We are interested in lower limb movements as they are more challenging to communicate over video. Video conferencing tools are typically configured to support talking heads conversations, and have little consideration for the observation of full body movements [4]. Moreover, video technology possess

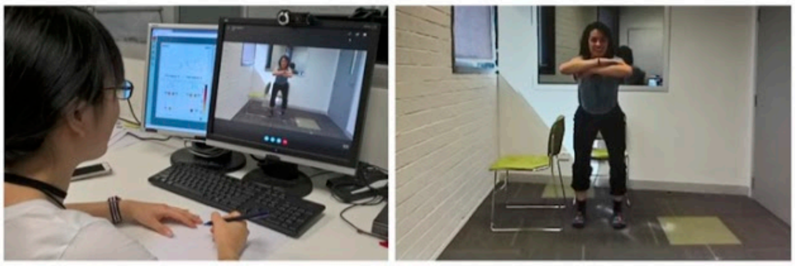

Figure 1: Setup of *SoPhy* during a video consultation: (a) In left, a physiotherapist is using *SoPhy* web-interface to understand patient's movements. (b) In right, a patient is performing lower body movements by wearing *SoPhy* socks.

limited visual acuity that further reduces clinician's ability to discern subtle changes in exercises e.g., point of balance and depth of squats [2].

This is the first attempt that extends video consultations beyond audio-video medium and explores the potential of a wearable technology to support the tasks of physiotherapists. We designed *SoPhy* that provides information of key aspects of lower limb movements during video consultations (refer Figure 1). We conducted a laboratory study to investigate how *SoPhy* helps physiotherapists in assessing patients over video [1]. The findings showed that *SoPhy* increased their confidence in assessing low limb exercises like squats, and they required fewer repetitions of exercises to assess patients with *SoPhy*. Next we illustrate the design of *SoPhy*.

2 SoPhy: Our Proposed System

SoPhy stands for 'socks for physiotherapy'. *SoPhy* is a novel wearable technology consisting of (1) a pair of socks embedded with three pressure sensors and one Inertial Measurement Unit (IMU) that patients wear while performing lower body movements (Figure 2a); and (2) a web-interface that visualizes information about weight distribution, range of foot movement and foot orientation to physiotherapists in real-time (Figure 2b).

We have followed user-centered approach to iteratively design *SoPhy*, and collaborated with a senior physiotherapist (last author) at a leading hospital in Australia. To this end, the selection of different sensors and visualisation of the data are the results of multiple lab trials and feedback from the collaborating physiotherapist. Below we describe the bodily information supported by *SoPhy*.

Weight Distribution: Weight distribution describes the amount of weight a person bears in different areas of the foot e.g., on toes, balls and heel. While a healthy person distributes equal weight on each foot (leg), the pattern changes in case of an injured. For instance, if a person has injured his big toe, he may bear more weight on the outside of the foot. *SoPhy* captures the pattern of weight distribution on the balls and heel of the foot, through pressure sensors stitched on the *SoPhy* socks. The web-interface displays weight distribution on the feet sketches showing the feet from underneath

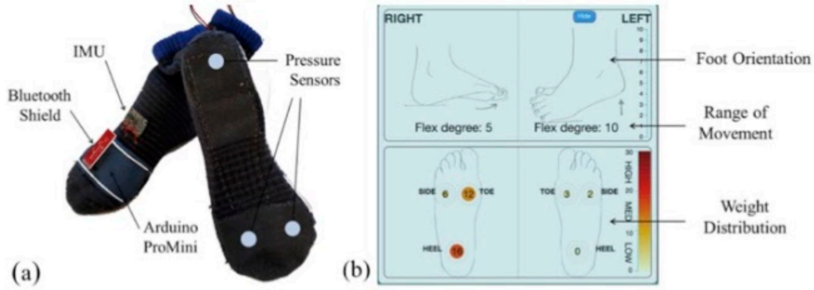

Figure 2: *SoPhy* consists of two parts: (a) a pair of socks with sensors embedded, and (b) a web-interface that visualizes the information related to foot orientation, range of movement and weight distribution.

(refer Figure 2b). For each sensor, the pressure values are presented with a number on a scale of 0-30 and on a color spectrum of yellow to red.

Foot Orientation: Foot orientation refers to the alignment of foot in four directions. First is the dorsiflexion, which occurs when the person bears weight on the heel of the foot with toes lifted up in the air. Second is the plantarflexion where the weight is on the balls and toes of the foot with heel lifted up in the air. Third is the medial orientation where the weight is on the inside of the foot and the person lifts the outside of the foot up in the air. And final orientation is lateral orientation where the person bears weight on the outside of the foot and lifts the inside of the foot up in the air. In *SoPhy*, foot orientation is captured by the IMU sensor sewed on the socks on the bridge of the foot. We have used multiple foot sketches to present this information on the web-interface: three each for dorsiflexion and plantarflexion, and two each for medial and lateral orientation (refer Figure 2b).

Range of Movement: Range of movement refers to the magnitude of the foot orientation across four directions described above. The range is defined on a scale of 1 to 10 and is calculated from the IMU data. On the web-interface, this value is represented as a 'Flex degree' under each foot (refer Figure 2b).

3 Engaging with SoPhy

Figure 1 shows the setup of *SoPhy* during a video consultation. The patient wears the *SoPhy* socks before starting the video consultation with physiotherapist. During a video consultation, physiotherapist will ask the patient to perform different lower body exercises, e.g., dorsiflexion and plantarflexion, squats, and heel raises (refer Figure 3). As the patient performs these exercises, the socks capture data about foot movements. This data is then sent to the web interface, where the physiotherapist can see the movement data in real-time. We designed a mobile app to support data communication between the socks and web interface via a Bluetooth shield attached on the *SoPhy* socks.

At the venue, visitors will be able to try out *SoPhy* in solo or in pairs. They can wear the *SoPhy* socks and check the visual feedback on the web-interface for different lower body movements. Alternatively, they can role-play as a physiotherapist and

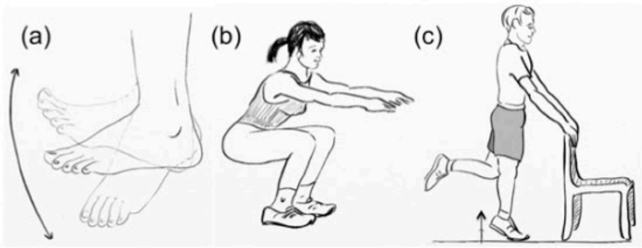

Figure 3: Examples of lower limb exercises: (a) Dorsiflexion and Plantarflexion, (b) Squats (c) Single leg heel raises.

patient, to mimic a clinical consultation related to lower limb assessment. We anticipate that audience will get the following insights by interacting with *SoPhy*:

1. They will get an awareness of the role of different bodily cues related to lower body exercises.
2. They will become familiar with the emerging practice of video consultations and the challenges of video technology in communicating lower limb movements.
3. They will gain insights on the challenges faced by physiotherapists in assessing patients during video consultations, and how *SoPhy* can help them in their decision-making process.
4. They will get a first-hand experience of *SoPhy*, which will particularly, be of interest to DIY med-tech community.
5. Finally, it will potentially seed new interests and conversations around the development of future video consultation systems that provide essential bodily information to clinicians.

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