TelePhysio+: Exploring Changing Perspectives of Remote Physiotherapy

by

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Abstract

Physiotherapy is traditionally performed in person, allowing physiotherapists to easily guide patients into the positions that are required for assessment. However, some circumstances prevent in-person sessions from taking place, such as living in rural areas with limited access or experiencing health-related barriers (e.g., lockdown due to pandemic). To accommodate demand for remote care in these circumstances, remote physiotherapy consultations can be supported by video-conferencing software and monocular webcams. In addition to preventing therapists from being able to physically touch their patients, remote physiotherapy supported in this way forces interactions into a 2D space, which constrains physiotherapists' view of their patients, limits bodily communication, and further reduces their control over a session. The nature of these interactions makes it challenging for physiotherapists to view a patient with enough fidelity to enable assessment, due to issues with latency, lighting, and field of view. While previous research has identified these issues as communicative barriers, solutions have often excluded the perspectives and needs of physiotherapists by focusing only on patients. We present TelePhysio+: a platform that addresses many of these obstacles, from the physiotherapist's point of view, by incorporating three-dimensional visualization through full-body tracking and allowing physiotherapists to directly control their perspective of the patient. Using this system as a probe, we present findings pertaining to physiotherapists' views on remote physiotherapy, challenges encountered in transitioning from in-person to remote physiotherapy, and aspects of remote physiotherapy they find problematic. Through our iterative design process, we also present design guidelines to help address physiotherapist needs, particularly with regards to engaging with 3D body tracking information, controlling patient perspectives, and managing patient information.

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Chapter 1

Introduction

As the global population ages, the demand for physiotherapy has grown [36]. However, in remote and rural communities, access to in-person physiotherapy has decreased, as physiotherapists often prefer to work in urban areas [9]. Older patients, as well as patients suffering from a variety of conditions requiring physiotherapist intervention, often face barriers in travelling to physiotherapy clinics. This highlights the need for effective remote physiotherapy tools to assist patients. While not a primary motivation for our work, the COVID-19 pandemic has also emphasized this need. Continued accumulation of these scenarios has led to the adoption of remote sessions as a way to improve physiotherapy access. However, previous research has found that video-based remote healthcare sessions in general are encumbered by issues involving camerawork (i.e., positioning the camera), visual acuity, and difficulties in managing the flow of a session [3], and it is likely that similar challenges are encountered by physiotherapists.

Previous research has explored 3D body-tracking as a means to allow technology-augmented physiotherapy interventions. This research includes studies involving on-body sensors [37] and encumbrance-free approaches using the Microsoft Kinect [33, 4, 16]. While this research considers remote physiotherapy as an important use case, three aspects stand out as gaps in the work. First, evaluation of novel approaches focuses on the patient experience. While this is an important facet of physiotherapy, it only considers one side of a two-way interaction. The outcomes of the research provide valuable insights into the patient's experience, but there is considerably less information surrounding the experiences of clinicians working with patients' body-tracked data. Second, most of the existing body of research does not look specifically at synchronous remote physiotherapy sessions, even while these types of physiotherapy sessions become increasingly available for patients [2]. More often, the examined remote scenario is asynchronous, such as 3D guidance for unsupervised at-home physiotherapy activities [33, 32]. Third, in evaluating proposed approaches, an athletic activity such as dance or martial arts is often used rather than focusing on physiotherapy specifically [4, 16]. The presented work addresses these gaps by focusing specifically on physiotherapists' experiences in synchronous remote sessions, and by using common physiotherapy exercises as a baseline for designing a proposed solution.

By examining the physiotherapists' perspective, important considerations may be revealed. For example, what challenges do physiotherapists currently face in performing physiotherapy remotely, and what strategies do physiotherapists employ to overcome them? How do these communication dynamics compare to in-person sessions, and how should supporting technology be adapted to better support physiotherapists and, by extension, patients? To address these questions, we undertook two studies. First, we used thematic analysis of interviews of physiotherapists with experience in remote care to identify key obstacles they faced. Second, we used our findings to conduct an iterative user-centered design process with physiotherapists, to produce a body-tracking system for video-based remote physiotherapy. The resulting system, TelePhysio+, uses a low cost depth-sensing camera and allows physiotherapists to engage with multiple viewing perspectives of a 3D patient model.

This allows physiotherapists to freely explore a patient without having to engage in cumbersome instructions to guide them into position, to frame the camera, and to document their progress. Further, we provide additional support for physiotherapists needs by including note-taking and the collection of movement data as features, along with the ability to generate personalized patient feedback. We again used a thematic analysis of views physiotherapists shared with us as we demonstrated the tool and iterated over its features based on their feedback.

In this work we contribute findings that illustrate the communication barriers, strategies, and dynamics currently used by therapists in remote physiotherapy using conventional video conferencing software. Based on these findings, we present TelePhysio+: a novel system designed to support remote physiotherapy. We also report our findings from the iterative development process based on physiotherapist input, and use these findings to make concrete recommendations on improved support for remote physiotherapy systems by providing explorable 3D models of patients.

Chapter 2

Related Works

2.1 Challenges in Medical Communication

Communication between patients and healthcare providers has been the subject of research for some time. The inherent asymmetry between the patient and the clinician is an important consideration when designing communication technology. Through a literature review and interviews with clinicians in non-remote scenarios, Rajabiyazdi et al. [28] identified several aspects of the patient-clinician relationship which create disconnects in communication, including patient anxiety, differing expectations, and incomplete information. The authors included interviews with physiotherapists, but ultimately did not differentiate between physiotherapists, specialists, and primary care doctors in their results. The authors also didn't consider the scenario of communicating remotely, which has the potential to amplify these issues. The interactions supported by remote healthcare technologies must facilitate the differences in emotions and expectations between patients and clinicians, while maintaining the robust and accurate transfer of information.

While the bulk of research has focused on communication between doctors and patients, similar concepts also translate to physiotherapy. Aggarwal et al. compared bodily communication between clinicians and patients during face-to-face and remote physiotherapy sessions [3]. They found an important limitation is the extent to which body language is visible tends to be reduced in remote sessions, which forces physiotherapists to rely on a patient's ability to verbally articulate relevant information. Another key limitation they discovered was that video-based formats limited the extent to which physiotherapists suggested and demonstrated new exercises to patients. This was primarily due to fixed hardware configurations, which made it difficult to adjust the camera's view/perspective to show specific areas of the users' bodies. Some design guidelines are suggested, but specific solutions to these problems are not assessed by the authors. Our work goes a step further in identifying areas where improved information-sharing tools can enable more effective communication with patients.

A series of interviews by Zhu et al. identified challenges in remote prehabilitation [38], citing low patient motivation and engagement as specific barriers to overcome alongside challenges with assessment. In addition to a lack of sensors and measurement tools available for remote assessment, patient adherence and motivation to assigned activity is significantly more difficult for clinicians to manage during remote care. This is critical because patient engagement is frequently identified as a determining factor in physiotherapy outcomes [34, 26]. A key finding related to our work is that healthcare experts want more options for enabling patient assessment using videoconferencing software, and were open to novel interfaces. However, the development and exploration of potential interfaces was not included in the work reported by Zhu et al. [38].

Remote assessment has not been researched or refined as much as patient engagement, but some work exists which compares in-person patient assessments with remote patient assessments. A comparison of evaluation outcomes for knee replacement patients found that for 5/8 outcomes, the inter-rater reliability for remote evaluations was comparable to or greater than that of in-person evaluations [8]. This work avoided instrumented or sensor-based approaches to remote assessment (for example, to assess range of motion remotely, a goniometer placed on the physiotherapist's screen).

2.2 Telehealth and Remote Physiotherapy

Telehealth has been implemented primarily using videoconferencing or data sharing platforms [17]. While several papers examine user acceptance [18], feasibility [12], and accessibility [14] in telehealth, very few have presented designs or interactions which improve traditional videoconferencing scenarios. A technical report by Dillman and Tang [11] presents physiotherapist opinions of three possible augmentations for video consultations, including shared mirror, annotation, and target placement, finding that augmented video could improve physiotherapists' effectiveness in several physiotherapy scenarios.

Despite a lack of physiotherapist-focused technical artifacts in prior research, a variety of work examines remote interactions to generate design considerations for future implementations. Han et al. used contextual interviews to demonstrate physician concerns around camera work with mobile devices, privacy, and workflow control [15]. Another paper explored issues of trust, time and space limits, and ease of access in e-mediated communication between doctors and patients [5]. These works show that changing social expectations in remote contexts can have an impact on patient-clinician interactions.

Previous literature has also established a general idea of what types of movements are appropriate for telehealth interventions. Gross movements involving large joints can be reliably assessed remotely, based on inter-rater reliability studies comparing in-person evaluation results to remote evaluation result [21]. This applies to both range of motion and functional assessments. Since most previous research focuses on a single condition or scenario, our work seeks to identify the broader needs of physiotherapists and how they might be supported, including other types of movements that might not be assessed as accurately when remote.

2.3 Body-tracking for Physiotherapy

Body-tracking using a depth-based camera (e.g., the Microsoft Kinect) has been established as viable for assessing gross movements for physiotherapy, particularly for orthopedic and rehabilitative scenarios [27, 13, 10]. Because of the relatively low cost involved in using depth-based cameras, as well as the robust development tools associated with particular hardware like the Microsoft Kinect [24], they have seen use in remote physiotherapy research [33, 4]. However, depth-based cameras are not readily available for generalized at-home care, as most patients would not have access to them. While our work primarily uses the Kinect platform to explore various aspects and improvements for remote physiotherapy, we also explored novel monocular computer vision approaches to low-cost, non-instrumented body-tracking. The most readily available platform, and the one we implemented as part of our work, was VNect [23]. In the authors' assessment of this model, they found the overall accuracy and stability of their body-tracking to be comparable to Kinect-based body-tracking, with noted improvements for limb occlusion and field of view. A full assessment of these platforms is not in the scope of our work, but we consider monocular webcams as a potential fallback for our Kinect-based body-tracking, in anticipation of further research and development making these types of platforms more effective and easier to implement in consumer-ready platforms. Further consideration of these two approaches can be found below (see *Study 2: Participatory System Design*).

2.4 3D Visualization for Physiotherapy Patient Guidance

Two applications, Physio@Home and YouMove both implement augmented mirror displays to provide exercise and movement feedback to patients [33, 4], and while similarly motivated, they take different approaches towards providing guidance. Physio@Home provides realtime feedforward and feedback visualizations to improve the accuracy of shoulder rotation exercises, while YouMove provides body frame data and annotations to the user for both abstract and exercise-specific movements. Both applications use a motion capture setup to collect user movement data. YouMove additionally provides training materials in its patient-facing application, but no evaluation was performed on the efficacy of the tool. Sousa et al. used a projected AR setup to guide arm rotation exercises [32]. A wearable sleeve was used to capture user data, which affected visual feedback projected on the ground in front of the user. AnatOnMe, arguably, also qualifies as a 3D visualization tool, but the associated research focused on education and engagement rather than movement or posture guidance.

Immersive VR research also incorporates 3D bodytracking, and has been more focused on rehabilitation for cognitive-motor conditions. VR allows visuomotor discordance to be used in stroke rehabilitation, which combines motor control training with mismatched cognitive responses, improving the development of damaged cortical connections [35]. When used in gait training, VR can reduce fall risk and improve functional performance in patients with Parkinson's disease [25]. Hoang et al. explored the use of body-in-body manipulations of user embodiment to support one-to-many exercise instruction in VR, focusing specifically on martial arts postures [16]. The latter is not directed at physiotherapy, but aligns with the communication dynamic of an expert user remotely guiding a novice through movements and exercises using 3D bodytracking.

While the work in 3D visualization for physiotherapy has provided interesting insights into the effectiveness of various approaches, these have almost exclusively focus on the patient perspective. Among works which evaluate an expert-facing component for their respective systems, an evaluation of user experiences are limited in scope and are not the primary focus of the work [4, 1]. In our presented work, we explore how 3D visualizations can be used by physiotherapists to help improve communications during remote physiotherapy, with a focus on user experiences among physiotherapists who work with patients remotely, or who have adopted remote physiotherapy technology in response to the COVID-19 pandemic during 2020.

Our contribution to this space is in the form of two studies and a novel software prototype. Our studies were conducted with the goal of exploring the challenges, needs and expectations that physiotherapists face in providing remote care using status quo technology, and to demonstrate how they can be practically addressed with (relatively) low cost hardware. The underlying assumption for our work is that physiotherapists' assessment of and care for their patients is impeded in some ways during remote sessions, and that communication and information-sharing mechanisms are poorly supported by, or incompatible with, conventional teleconferencing software that is used in remote physiotherapy software. Where other research has sought to improve the patient's ability to receive information, the ability for physiotherapists to provide information is under-explored. Our first study consists of semi-structured interviews to explore physiotherapist perspectives of remote physiotherapy more thoroughly. Our second study applies our findings to initiate a participatory design process, where physiotherapists were able to evaluate and critique a remote physiotherapy system design as it was developed.

Chapter 3

Study 1: Understanding Physiotherapists' Needs During Remote Physiotherapy

3.1 Methods

To build an understanding of physiotherapists' needs in conducting remote physiotherapy and how they might best support their patients, semi-structured interviews were conducted with seven physiotherapists. Participants were recruited through snowball sampling, starting with the authors' professional contacts, and based on availability. For study 1, only participants who had some experience delivering physiotherapy remotely were recruited; and, included those who had only started to use remote physiotherapy after the onset of the COVID-19 pandemic in 2020. This criteria resulted in seven physiotherapists participating from three different Canadian provinces, before data saturation was reached. This allowed us to ask targeted questions about practical aspects of remote physiotherapy, or about changes to remote physiotherapy practices as a result of increased adoption due to the pandemic. In-

Table 3.1: Participant Profiles for Study 1

Participant Code	Specialization	Years of Physiotherapy Experience	Region	Gender
P1	Inpatient Neurologic	9	NS	F
P2	Outpatient Orthopedic	6	NB	M
P3	Outpatient Orthopedic	4	NB	F
P4	Outpatient Orthopedic	7	NB	M
P5	Outpatient Geriatric	23	NS	F
P6	Pediatric*	30	AB	F
P7	Outpatient Orthopedic	8	NS	M

terviews were performed remotely using Skype video calls between April and June 2020. Participants were also asked to describe and demonstrate their process for remotely providing diagnoses, support, evaluations, and exercise guidance to their patients.

3.1.1 Participants

Seven physiotherapists were recruited for this study, as shown in table 3.1. Five of seven participants practiced at privately owned outpatient clinics, one practiced in a hospital (P1) and one practiced in a public school system (P6). All participants reported some amount of experience with remote physiotherapy prior to the 2020 COVID-19 pandemic, which led to participants' practices becoming mostly or entirely remote. Prior to the pandemic, remote sessions were administered on an as-needed basis, usually on patient request. No participants had received training specific to remote physiotherapy, although 2 participants had attended workshops on setting up their home environment for remote physiotherapy during the COVID-19 pandemic.

3.1.2 Procedure

Interviews began with the collection of demographic information, including years of physiotherapy experience, participant location, a summary of participants' current physiotherapy practice, and a summary of participants' experience with remote physiotherapy. This was followed by a more detailed discussion of in-person practices, common patient conditions, and commonly prescribed exercises. Where possible, participants were asked to demonstrate exercises of their choosing, which helped transition into a discussion of remote physiotherapy practices. The participants' demonstrations provided a common reference when discussing challenges in video-based remote physiotherapy.

At the end of each interview, we asked participants to consider a prototype for remote physiotherapy interactions based on a two-minute video. The demonstration introduced VR as a medium and demonstrated two models moving around in VR acting as a physiotherapist/patient pair, with body-tracked models being visible to each user (similar to the implementation of OneBody [16], although presented with a focus on one-to-one physiotherapist-patient interactions instead of the one-to-many scenario described in that work). The highly flexible user perspective (supported by VR) in this type of application presented interesting design implications for our research. The goal for this portion of the interview was to explore the ideas of 3D visualizations, mixed reality, and perspective control to support remote physiotherapy, and whether physiotherapists felt these technologies could improve their ability to view and assess their patients. Additionally, we sought to elicit direct comparisons between 3D visualization systems and status quo 2D video-based systems. A screenshot of the presented prototype system is shown in figure 3.1.

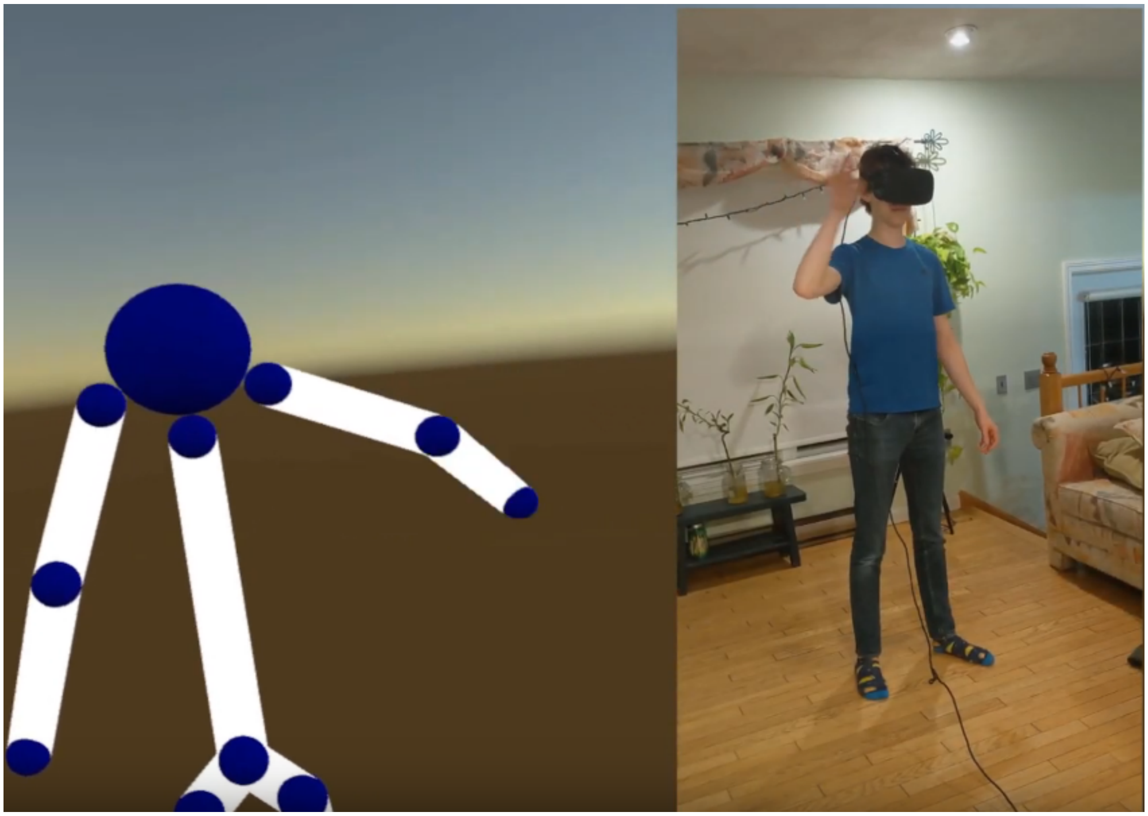


Figure 3.1: A still from the demonstration provided to participants in the first study. Shown from the user's perspective in VR, the figure shows a second user with movements displayed through body tracking.

3.1.3 Data Collection and Analysis

Both audio and video recordings were produced from each interview. The audio recordings were transcribed for analysis, and supplemented where needed with descriptions of participant actions from the video recordings. A deductive approach [6, 30] was employed for thematic analysis of the transcribed interviews. A deductive approach refers to the process of starting with a set of codes based on a theoretical understanding and aligning with the main interests of the study. Initial codes can then be iterated upon and further developed during the analysis when warranted. When these iterations occur, researchers involved in coding were responsible for retroactively applying modified codes to previous interviews.

For our analysis, our initial codes were created based on existing literature, and further broken down based on initial assumptions, or to best capture the desired level of granularity in our coding structure. As an example of the former, codes involving touch were divided to capture perspectives of touch in physiotherapy, clinical outcomes of using touch, and barriers created by the lack of touch in remote scenarios. Meanwhile, codes involving camerawork were divided into field of view, visual acuity, perspective, and lighting. A complete list of codes is presented in table 3.2. Codes were independently applied to the interviews by two researchers, with a IRR of 0.88, as calculated using the methods described by McAlister et al. [22]. Codes that were in conflict were resolved through consensus after all interviews had been analyzed. While our initial codes reflect our themes based on our understanding of existing literature, our final themes were based on a reflexive analysis of coded semantic content. This reflexive consideration of themes and codes is based on Braun and Clarke's 2006 paper describing thematic analysis [6], and is further supported by their 2019 reflection on this methodology [7].

Because the timing of the interviews coincided with the early stages of the 2020 COVID-19 pandemic, we included codes to capture changes in physiotherapy and remote practices as a result of the pandemic. These changes were not a direct focus for our research, but helped to provide context during our analysis. Detailed descriptions for each code can be found in our additional materials. As discussed in chapter 2, previous work mostly focuses on remote physiotherapy from a patients perspective. We chose to utilize challenges identified in previous work (such as visual acuity [3]) to make assumptions about codes that might present themselves in our interviews. To improve our initial codes, we also considered work that examined telehealth more broadly, such as research by Andreassen et al.[5] and Aarhus et al.[1]. Where previous work designed patient-facing tools, we condensed their presented design considerations (such as the use of multiple camera angles) to create codes surrounding touch and camerawork [33]. Finally, we included codes which were not rooted in theory, but intended to capture new information generated during the COVID-19 pandemic, which prompted wide-scale societal adaptations shortly before our research commenced in 2020.

Our initial high-level codes included:

- Camera Work (including visual acuity, field of view, and perspective) [3, 33]
- Boundaries in Remote Physiotherapy [5, 1]
- Environment [5, 1]
- Touch as Part of Physiotherapy [33, 9]
- Perceptions of Technology [15]
- Changes to Physiotherapy During COVID-19

Analysis was performed throughout the interview process, with coding of previous interviews being finalized prior to successive interviews. As analysis continued, these codes were reorganized to facilitate analysis by eliminating fully redundant codes and creating clearer distinctions between related codes. Codes which were noticeably more frequent were broken down into sub-codes as researchers familiarized themselves with incoming data. These iterations were necessary after interviewing P1, P3, and P4, and changes were retroactively applied by each rater to previous interviews. Documentation of these changes, as well as the rationale for each change, has been included as additional material. Recruitment and interviews were halted when data saturation had been reached; meaning that new information was specific to the participants' individual practice, and the information being coded was largely reiterating the information provided by previous participants.

Table 3.2: Initial Breakdown of High-level Codes

Initial Code	High-level Code	Code
Camera Work	Camera	Camera.Perspective Camera.Lighting Camera.FOV Camera.Details Camera.Other
Boundaries	Time Telehealth	- Telehealth.Integration
Environment	Environment Exercises	Environment.Patient Environment.Physiotherapist Exercises.Tools
Touch	Touch	Touch.Outcomes Touch.Perceptions Touch.Barriers Touch.Other
Perceptions of Technology	Technology Telehealth	Technology.Perceptions.Patient Technology.Perceptions.Physiotherapist Technology.Features.Software Technology.Features.Hardware Technology.InClinic Technology.Intersession Telehealth.Perceptions Telehealth.Comparisons
Changes to Physiotherapy During COVID	HealthConcerns	-

3.2 Results

3.2.1 Opinions on Physical Contact

Physiotherapy is typically viewed as a hand-on practice, and this was reflected in participants' responses. The primary challenge that was identified in remote care was the inability to touch the patient, for a variety of reasons. Participants cited exercise guidance, feeling muscle activation, and hands-on assistance (such as applying overpressure to a joint) as important touch-based components of in-person physiotherapy. Participants also referenced a "healing hands" effect, where patients receive a beneficial placebo effect from having a physiotherapist touch them. P3 said "I think most of the research has shown, it's not exactly what you're doing in terms of manual therapy, just the fact that we have hands on people seems to help".

Despite the importance of touch, physiotherapists have adapted to remote work, and have changed their views on the importance of physical contact. Participants reported being wary of remote work, or otherwise reluctant to switch to an entirely remote practice, but most were more enthusiastic about incorporating remote sessions after being forced to adopt them during COVID-19 lockdowns. P2 described the initial adoption process, saying "I was a little bit skeptical at first just because physiotherapy is built on in-person interaction, and most of us are quite hands-on and much of the field is around manual skills and manual therapy, but that being said I've been pleasantly surprised". When asked if they would have adopted remote physiotherapy without the pressures of the pandemic, P7 said "I feel like if this whole pandemic didn't happen, and someone would have asked me if I wanted to do it, I would have still said 'yes', but I feel like it wouldn't be utilized very much".

With regards to future adoption or development of remote physiotherapy services and supporting technologies, participants' views were mixed. Some participants referenced job satisfaction as a significant motivator for in-person sessions, and said that they wouldn't enjoy working remotely for a sustained period of time. Other participants were more optimistic about the benefits of remote physiotherapy, but expected that significant cultural changes would be required for adoption. P4 suggested that "[Our] profession is over-reliant on hands-on treatment and manual treatments. [That's] going to have to change".

Participants also discussed challenges in changing patient perceptions of physical contact, since these perceptions were a barrier to remote adoption during lockdowns. A wide range of issues were discussed with regards to patient adoption, many of which related to patient understanding of how physiotherapy could help them and how it could be delivered remotely. According to participants, some patients had misconceptions of how their body worked, and therefore believed that physiotherapy would not work without physical contact. Other patients faced barriers in their use of technology, and did not want to deal with difficult setups for remote physiotherapy applications.

3.2.2 Challenges in Camerawork

Existing literature suggests that two key challenges in video-based physiotherapy for patients stem from singular perspectives and poor visual acuity [33, 3]. Our results support these previous observations from the physiotherapists' perspective. With regards to camerawork, participants identified issues of field of view and camera angles as distinct challenges in their remote sessions. In a pediatric setting, P6 reported a reliance on a 3rd party to obtain suitable camera angles using a single camera, which required significant back-and-forth communication and took time out of their sessions. P3 also discussed the challenges associated with having a single video perspective, and went on to mention the challenge of remaining in view while transitioning from standing exercises to seated exercises. This seemed to be a challenge for both physiotherapists and patients. As P2 described, "[It would be helpful to] just be able to click a button and be able to say okay, follow my movement as I go, so that I'm not adjusting the camera up and down every time. Or moving the camera to a floor, so when I'm in a seated position on the floor to show a stretch or something like that, that's probably been one of the biggest challenges".

Frequent camera adjustments are the only practical work-around for these issues. While most users are able to see their own video feed and adjust accordingly, physiotherapists report recurring time losses from communicating camera instructions to patients. Discussing the need for camera adjustments, P3 said "You can see yourself, so you can be okay, but I guess it'd probably take like 10 to 15 more seconds". Both patients and physiotherapists are mindful of the cost of a physiotherapy session, and the time-limited nature of most sessions makes camera adjustments and the associated communication feel like a wasteful process. Furthermore, frequent changes in perspective, combined with the difficulty of resolving a 2D video feed to 3D anatomical understanding, creates a scenario which P5 described as "mentally exhausting".

The other challenging aspect of video-based physiotherapy is the video itself. Visual acuity can be diminished by poor camera quality, poor lightning, slow internet connection, or delayed camera focusing. P4 recalled "I have [one patient] who could not figure out her camera [and] I assessed her over a dark screen, so it might as well be a phone call". While most patients have a camera available, P2 said that "Sometimes they're really low quality, so that's where it gets difficult to really assess things". Physiotherapists have access to educational resources focusing on optimal camera angles and lightning for demonstrating exercises to patients, but there are no analogous resources available for patients.

3.2.3 Accessibility for Patients

Some participants identified flexibility as a major benefit of remote sessions. Patients who are working from home with children are less able to partake in physiotherapy during typical business hours. When physiotherapists are able to work remotely from their own homes, it can be more feasible to accommodate abnormal times. Similarly, patients who live in rural areas or who rely on family members for transportation can attend remote sessions more easily. Even patients who do not typically face barriers to in-person sessions may benefit from greater flexibility through remote sessions. P7 described the situation of an athletic patient who had to travel to another province for work, and subsequently had to self-isolate for a substantial time. For this patient, it was beneficial to have shorter, more frequent remote sessions, as opposed to a typical longer in-person session. These accommodations are easier to provide remotely, where time and space constraints are less of a barrier.

3.2.4 Intersession Resources

Every physiotherapist interviewed reported using digital handouts (e.g., PDFs) and videos, selected from an online database (such as Physiopedia or YouTube, or an application such as HEP2go), as added resources to provide to patients. While these handouts are sufficient as supplements between in-person sessions, participants identified additional tools as key components of remote physiotherapy programs. Most remote physiotherapy software allows screen-sharing, enabling physiotherapists to walk a patient through a demonstration video without performing the exercise. Some participants use additional apps or models enhance this process. This serves as a replacement for physiotherapists using their own body or the patient's body to provide information during collocated sessions. While these tools can facilitate certain types of information-sharing, other types of information cannot be conveniently collected and shared between sessions.

Another valuable form of information shared between sessions are notes collected by the physiotherapist. 5 of 7 participants reported adding notes and feedback to emails exchanged with patients after sessions. Despite the prevalence of this practice, physiotherapists found that it was harder to perform sessions remotely and capture notes synchronously. In remote sessions, note-taking is often a separate task requiring a different application, which consumes more of the physiotherapist's time and resources (including screen space or attention). In a collocated scenario, note-taking can be done in collaboration with the patient, often serving as an interactive teaching activity as well as a record-keeping task. P3 explained that "it takes a lot of time to record [non-digital] notes after a session [...] doing it during a session would require opening another window which blocks [the video from the patient]". P4 identified this as an area for improvement for remote physiotherapy software, saying that it would be useful to be able to record notes on the same screen, alongside the videoconferencing tool. P5 went a step further, and described the disconnected nature of information management for their remote practice. As they said, "I'm juggling all different types of forms, on my phone, the iPad, the computer, I'm juggling [...] all different programs, you know. Just to make it work".

3.2.5 Assessments and Tracking Progress

Assessments are usually performed using standardized tools or tests, and are important to track and demonstrate a patient's progress. In remote sessions, these tests are replaced by more subjective visual assessments. While many physiotherapists find this sufficient, patients often want an objective way to show their progress between sessions. P2 said, "The best example is when they're still in pain, but their range of motion has improved, and when you point it out, even if it is a difference of your shoulder was [bent at 90 degrees] and now you're [bent at 95 degrees], it's… an easily visible change. If they come in [virtually] next time it's [slightly higher] and

I'm trying to measure that on camera, that's a harder conversation to have... "well it seems like it's a little bit better"... and that's when an actual measure would be really nice to have". Screenshots are a potential solution that was explored by some participants, but they were ultimately too difficult to reliably set up in a way that was consistent between sessions.

3.2.6 Control in Remote Sessions

One theme which extends into several facets of remote physiotherapy is that of control. In our interviews, participants discussed different ways that communicative asymmetries diminished their control during remote sessions. The most frequent example provided was the use of touch as a way to guide the patient towards different placements to improve a physiotherapist's perspective, or to accelerate guidance phases of a session. P3 reported that, "I had to think about [...] making my exercises more basic, because it's hard to not be able to put your hands on people and to give them cues. It's just a bit different in terms of how to show exercises when you're not able to be right there with the person [...] but it hasn't been as bad as I thought it would be. A bit easier than I thought.". In addition to the lack of touch as a control mechanism, physiotherapists face latency in communication, which extends the time required for most interactions. Finally, the different social expectations presented in remote interactions can make it more troublesome to direct the flow of a session from one phase to the next. According to P2, "Probably the biggest issue I have is the transition from having a conversation. [Going from] the subjective part of our conversation, and then transitioning into assessing their movement or demonstrating activities", referring to the challenge of guiding and redirecting conversation while dealing with network latency and modified social dynamics in remote sessions. Our participants also identified camerawork as being a barrier in this regard, where a camera positioned for face-to-face conversation might not be suitable for demonstrating or explaining exercises. Aggarwal et al. captured similar sentiments when describing "clinical asymmetries" during their investigation of remote healthcare [3].

3.3 Discussion

We discuss our results in terms of eight proposed design goals for remote physiotherapy solutions. Our thematic analysis identified obstacles and features that physiotherapists encounter in remote sessions, which we condensed into design goals for improving physiotherapists' experiences. We placed these design goals into categories of "accounting for lack of touch", "measuring progress", and "managing camerawork".

3.3.1 Accounting for Lack of Touch

- **A1 - Facilitate control over the flow of a session.** Physiotherapists use touch and physical cues to establish control over assessments. Current remote physiotherapy software relies on verbal communication to facilitate assessments. Adding more ways for physiotherapists to control a session can mitigate some of the problems introduced by removing physical touch.

- **A2 - Provide additional mediums for sharing information.** In the absence of touch, physiotherapists will sometimes reduce the difficulty of prescribed exercises. In order to facilitate more advanced exercises in remote scenarios, physiotherapists need additional tools to obtain information and provide feedback to patients.

3.3.2 Measuring Progress

- **B1 - Provide fixed points of reference for visual comparisons.** When visual comparisons like screenshots are provided to a patient, they should have a fixed point of reference between sessions, to ensure easy comparisons. Physiotherapists often require patients to adjust their lighting, camera angles, and positioning just to get a screenshot for comparison. This process should be simplified in software implementations.

- **B2 - Enable standardized assessments.** Many physiotherapists have reduced the collection of standardized test results in their assessment. Some of these standardized measures could be facilitated by remote physiotherapy software, such as the measurement of range of motion at major joints. While some tests are impossible to facilitate using only software, even simple tools could be beneficial in facilitating more complex assessments, such as stopwatches that account for network latency.

- **B3 - Create processes for personalized assessments.** An alternate approach would be to develop measurement tools that function in a variety of contexts. Because patient goals are often tied to specific, personal tasks, it may be useful for physiotherapists to assess patients as they perform these tasks in various situations around their home. Processes and tools to facilitate patient-specific assessments should be a consideration in software design.

- **B4 - Allow flexibility in recording information.** Whether subjective or objective measures are used, physiotherapists need to record results, which often requires physical note-taking or using additional applications. Physiotherapists will often copy recorded results or observations into another document to be sent to patients. Remote physiotherapy software should incorporate these tasks and allow recorded measurements to be easily exported to an appropriate format, whether for insurance purposes or for patient use.

3.3.3 Managing Camerawork

- **C1 - Reduce camerawork frequency.** Camerawork is a costly task during remote physiotherapy sessions. Changing camera perspectives increases the effort required from physiotherapists, and back-and-forth communication with patients to obtain necessary camera angles consumes meaningful portions of a session's time allotment. Where possible, software-driven tools should seek to reduce the frequency of camerawork, possibly by providing physiotherapists with information that would usually be obtained through changing camera angles.

- **C2 - Preserve unmodified video display.** Where 2D overlays or 3D models of the patient are used, the visualizations can miss or obscure subtle details that can be useful to a physiotherapist. If this type of feature is implemented, it should not obstruct or replace the original video display.

In addition to the design goals related to lack of touch, we were surprised to find that physiotherapists were generally in agreement with the idea that "touch is overused in physiotherapy". Participants often commented that the use of touch was rooted in cultural preconceptions among both patients and physiotherapists. They also described a "healing hands" effect, where the act of physical contact makes patients feel more comfortable, even if the contact provides no other health benefits or outcomes. Our findings suggest that, even if the lack of touch in remote physiotherapy is an important limitation with no near-term solutions, it may not be as an important a problem as conventional wisdom may suggest. Further, given that remote sessions are now common and physiotherapists believe they are beneficial, the lack of touch does not seem to be an insurmountable barrier for remote physiotherapy overall.

Measuring progress is an important part of the patient experience, and physiotherapists want to evaluate different aspects of progress as accurately and efficiently as possible. Furthermore, insurance providers often require specific methods to be used for measuring patient progress, many of which are difficult to coordinate in remote sessions. The following design goals address issues of measurement and tracking patient progress remotely.

Finally, the issue of managing camerawork was discussed by all participants, leading to several insights. Many of the issues we identified were anticipated based on previous research. However, we were able to explore this subject in more detail by demonstrating an early prototype, which sought to address the issue of camerawork by using VR as a means to control camera perspective in remote physiotherapy. While this early design is likely an inappropriate solution (in the near term) for the majority of situations due to the hardware costs and setup involved, it helped further develop design goals involving camerawork.

3.3.4 Connections to Previous Research

Our findings are in alignment with those of previous work. While considering synchronous remote healthcare, Aggarwal et al. presented design sensitivities and suggestions regarding visual acuity, field of view, clinical asymmetries, and time sequence [3]. Our findings reinforce these sensitivities with greater granularity and more specific design goals, many of which relate to those suggested by Aggarwal et al. One particular area where we provide more extensive findings is in our exploration of synchronous data collection, presentation, and interpretation by physiotherapists in a general context.

We can also compare our design goals with physiotherapist feedback collected during the development of SleeveAR [32]. In evaluating their design, the authors interviewed a physiotherapist who provided positive feedback on the system's potential for creating patient reports and reducing the frequency of physiotherapist interruptions during exercises. While this portion of the authors' findings was brief, we find it reassuring that this feedback has similarities with corresponding design goal **B2** (*Enable standardized assessments*) and, less directly, **C1** (*Reduce camerawork frequency*). As the body of research continues to include additional examples of physiotherapist feedback, our work will serve as a valuable point of comparison to validate future results in similar ways.

While our approach, considering the physiotherapist perspective, stands in contrast with the development of patient-centered systems such as OneBody [16] and Physio@Home [33], we consider our physiotherapist-centered methodology to be complementary. We believe that, by improving the effectiveness of physiotherapists working remotely, patients will also benefit. One way to consolidate both approaches is by applying our presented design goals when evaluating novel patient-facing systems. For example, Physio@Home [33] reduces camerawork by including multiple camera views, as we suggest with design goal **C1** (*Reduce camerawork frequency*), but a physiotherapist may require a view of the patient without the patient-centered Physio@Home visualizations, as we suggest with design goal **C2**. Some consideration may also be needed with regards to how a physiotherapist may control the visualizations and information provided to the patient, in alignment with goals **A1** (*Facilitate control over the flow of a session*) and **A2** (*Provide additional mediums for sharing information*).

Chapter 4

Study 2: Participatory System Design

For our second study, we sought to engage physiotherapists in a participatory design process to further explore the design goals identified in study 1, as well as examine specific implementation details. After developing an initial prototype, we obtained feedback from 8 participants before creating our final design.

4.1 Initial System Description

In our first study, we identified design goals in the areas of *Accounting for Lack of Touch*, *Measuring Progress*, and *Managing Camerawork*. Our goal for the second study was to engage in a user-centered design process to develop physiotherapist-facing software which addresses the design goals we defined. Our initial design was based solely on researcher assumptions based on findings from study 1, while further iterations were based on a combination of our design goals and on participant feedback. Our design did not involve a patient-facing counterpart, as our focus was on physiotherapists needs and experiences in remote physiotherapy. Our vision for TelePhysio+ was focused on supporting a broad range of physiotherapy needs, while acknowledging that not all features would be compatible with more specialized aspects of physiotherapy.

From the outset, we decided that design goals involving *Lack of Touch* would be addressed indirectly, primarily because the technology to support more direct solutions is currently insufficient. Instead, we designed TelePhysio+ to support the social dynamics and flows of information which would usually be supported through physical contact. Elements of our patient-feedback features were created with these concerns in mind. This communication-first approach allowed us to fulfil our design goals and explore the needs of physiotherapists in this area. Because camerawork was identified as a substantial barrier to effective remote physiotherapy sessions, we developed a system which provided a 3D skeleton view of the patient alongside a normal 2D video stream. The 3D interface kept the camera centered on the 3D model and allowed users to rotate and zoom in and out on the model. This allowed physiotherapists to control their perspective without relying on cumbersome verbal communication. Additionally, when using the 3D view, physiotherapists could obtain angle measurements at articular centers (i.e., they could measure the range of motion). In our design, this feature was possible for knee, hip, elbow and shoulder joints. Joint measurement data included information on current joint angles, mean joint angles, and maximum joint angles, as measured from a user-determined point in time.

To generate 3D skeletons, we used a Microsoft Kinect camera and a VNect [23] model for pose estimation. The Kinect allowed for rapid development and iteration, and allowed us to explore the use of single depth sensing cameras, which would be more accessible and readily available than marker-based systems (e.g. Vicon). VNect was used to explore additional remote physiotherapy scenarios, as well as to demonstrate the feasibility of monocular 3D pose estimation in a remote physiotherapy scenario. 2D videos were recorded simultaneously with the 3D skeletons, to simulate the intended scenario of exercise assessment in a synchronous remote physiotherapy session.

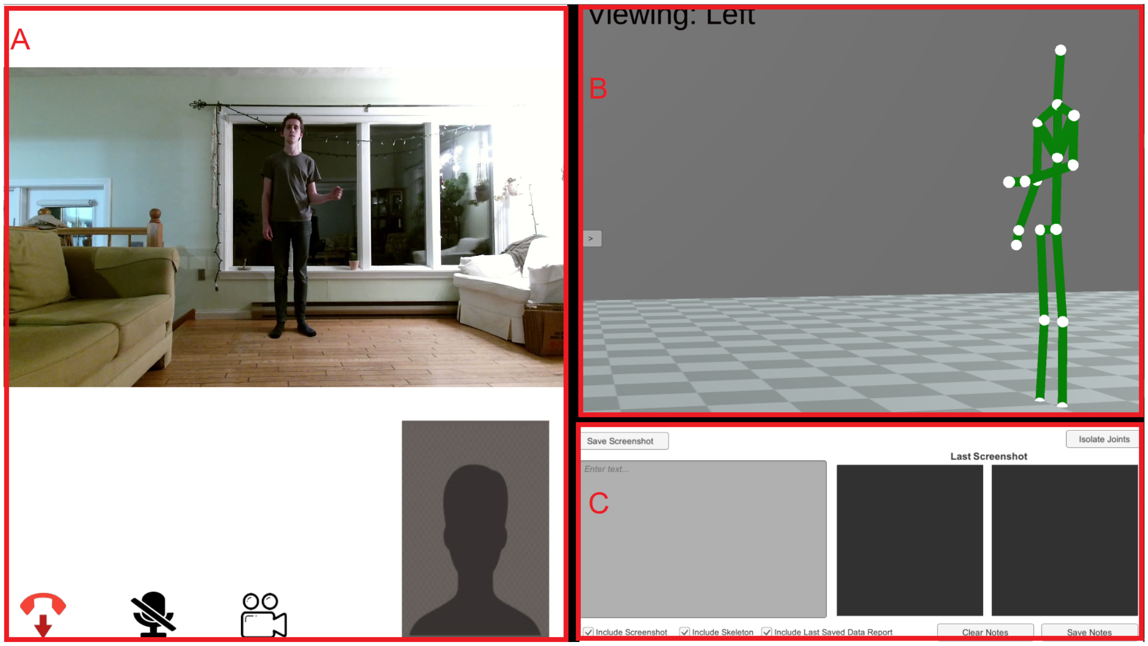


Figure 4.1: A screenshot of the complete system, indicating A. Video presented alongside additional features, B. 3D perspective view and body-tracked patient model, C. Patient feedback feature, interchangeable with joint data display

4.2 Methods

4.2.1 Participants

9 participants were recruited using snowball sampling. Of these 9 participants, 3 had participated in the preceding interviews. Participants 1, 3 and 5 in this study correspond to participants 1, 2 and 3 from the previous study, respectively. Participants were all actively practicing physiotherapists. 5 participants had previous remote physiotherapy experience, although only one had performed remote physiotherapy prior to the 2020 COVID-19 pandemic. Unlike in study 1, which focused on existing remote physiotherapy experience, study 2 did not have previous remote physiotherapy experience as part of the inclusion criteria. We sought views from a

Table 4.1: Participant Profiles for Study 2

Participant	Specialization	Years of Physiotherapy Experience	Region	Gender
P1	Inpatient Neurologic	9	NS	F
P2	Outpatient Orthopedic	8	NS	M
P3	Outpatient Orthopedic	7	NB	M
P4	Orthopedic and Palliative Care*	28	NS	F
P5	Outpatient Orthopedic	6	NB	F
P6	Orthopedic and Sport Medicine*	7	NB	F
P7	Orthopedic*	29	NB	M
P8	Outpatient Orthopedic	20	NB	M
P9	Outpatient Orthopedic	10	NB	F

* Participants reported both inpatient and outpatient specialization.

broader range of experiences, in order to capture participant views of new technology and their willingness to adopt it to support their practices. Table 3 provides additional information on participant specializations and years of experience.

4.2.2 Process

Each participant engaged in an interactive interview session. During each session, the interviewer used TelePhysio+ to display a series of exercise recordings (described below). Both 2D video and 3D model renderings were displayed. The interviewer controlled the 3D model perspective, and could optionally display detailed data about joint angles throughout an exercise. Participants were given a demonstration of TelePhysio+ through screen-sharing. Participants were encouraged to ask questions and direct the experimenter to interact with TelePhysio+ so they could explore its functionality. In addition to soliciting general feedback on TelePhysio+, we asked participants questions about how they might utilize the system, as a catalyst for exploring their views. For instance, in reference to specific features that participants were exploring, we often asked: “would this feature be valuable, if so, why”; “when would this not be valuable”; “what could change in order to make it more valuable”. After every 2 interviews, we performed an iterative update to the system to address gaps or problems identified by participants. A complete chronology of improvements with description of changes is included in the results section. In cases where two participants provided conflicting feedback, changes suggested by both participants were included. We asked subsequent participants to compare different implementations of these features, in order to determine which aspects of these implementations might be most valuable. Data collection was completed when no further improvements could be identified (within the scope of our project - see *Future Work*). Our final iteration was extended to include an additional interview (P9), in order to confirm that we had reached data saturation.

4.2.3 Exercise Recordings

Exercises were selected to cover a wide range of targeted movements, corresponding to conditions or anatomical groups that are frequently assessed in remote physiotherapy patients. These include back, shoulder, hip, knee, and elbow exercises. The selection of exercises was based on interviews in Study 1. Note that hand exercises were excluded, since the technology used in our implementation is unable to accurately capture precise hand movements.

All exercises were recorded under the supervision of a kinesiologist. The camera perspective used for these recordings reflected our findings from the first study, which indicate that physiotherapists prefer viewing some exercises from in front of the patient, and other exercises from multiple perspectives. Each recording also included a unique set of technical challenges, as identified in study 1, so that their impact on our system could be observed. Recordings of exercises were replayed in the system, as if they were being demonstrated by a live patient; i.e., the system was fully interactive. This allowed us to provide some control over the presentation of exercises across all participants.

The first exercise, depicted in figure 2a, was an assisted lateral shoulder abduction viewed from the front. This was meant to serve as a simple introduction to the system. Users were shown that the 3D perspective could ignore equipment used to support exercises, and that manipulating the 3D perspective could allow users to view the alignment of the patient's arm with the lateral plane. Users were also introduced to the joint data and feedback tools.

The second exercise, depicted in figure 2b, was a seated knee extension exercise, also viewed from the front. The lighting conditions were such that there was minimal contrast between parts of the patient's body - a common issue for video-based remote sessions. Users were asked how they would assess the patient as they performed this exercise. This helped to determine whether features would be used more than others, and whether there were relationships between how features were used.

The third exercise was a squat, as depicted in figure 2c, and served as demonstration of how the system handles differing perspectives and camera conditions. Multiple videos were shown, using different camera perspectives and video quality, in order to demonstrate some scenarios where the added tools might be useful. When demonstrating this exercise, in order to simulate scenarios where a patient has poor internet connection or a low-quality camera, we removed 1/10 of video frames at random, and down-sampled the video quality to 240p. The recordings with worse camera quality or choppy video helped to determine whether this type of technology could be a suitable option for patients without access to higher-fidelity technology, or without access to high-bandwidth internet connection, both of which were identified as common issues in Study 1.

After three design iterations, a lateral shoulder rotation exercise was added to better demonstrate the functionality of suggested features, including a plane deviation tool and sequential data display. This was a longer but more repetitive recording, viewed from the front, with 15 repetitions being performed. As more repetitions were performed, the actor slightly reduced the extent of their rotation. This simulates a usage scenario suggested by P5, where a patient experiences fatigue over the course of an exercise.

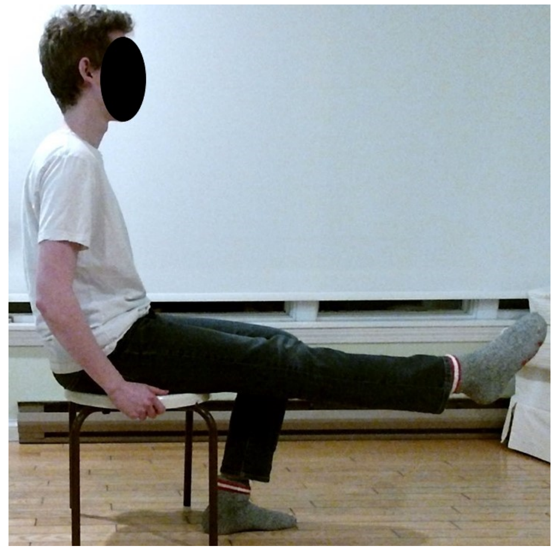
4.2.4 Data Collection and Analysis

For each interview, we collected audio and video recordings, which were transcribed for analysis. The transcripts were used for feature identification, which followed a similar procedure to the thematic analysis performed in the previous study. Transcripts were coded by a single researcher using Taguette [31]. Codes included comparisons to existing practices, negative feedback on features (including missing features), positive feedback on features, and reported usage scenarios.

4.3 Results

Participant feedback was generally positive. Features which received notably positive comments included 3D perspective controls, isolated joint data display, and patient feedback generation. While some participants identified improvements to these components of the system, these usually required no changes to the underlying framework of the system. The most substantial improvements were the addition of a target-based data display, a plane deviation display, and a sequential data display. Table 4.2 shows examples of participant feedback alongside the improvements made after each iteration. Early iterations tended to focus on improving aspects of the core functionality. Figures 4.3, 4.4 and 4.5 provide more detailed examples of added or modified features.

(a) Assisted Shoulder Abduction



(b) Seated Leg Raise

(c) Squat

(d) External Shoulder Rotation

Figure 4.2: Images showing the exercises used for demonstration. Exercises (b) and (c) are shown from the side for clarity. Exercise recordings were shown to participants from a head-on perspective.

Table 4.2: Relating Participant Feedback to System Improvements

Iteration	Summary of Feedback	Example	Design Improvements
1	It's unclear which side of the patient model is being viewed.	"It's a bit difficult to tell which side of the patient is being displayed in 3D." (P1)	Added 3D View Direction Indicator
	Should be able to include screenshots or pictures in feedback.	"[It would be helpful to] include screenshots or pictures in feedback." (P2)	Added screenshot creation, preview, selection, and export
2	The system should facilitate comparisons of joint angles to a target value	"It would be good to set a target [joint angle] for patients to meet." (P4)	Added Visual Joint Data Display
	Plane Deviation should be included with joint data to enable more complex measurements	"Another interesting value would be the deviation [of a joint or movement from a plane]" (P3)	Added Plane Deviation Display
	Click and Drag controls might be more familiar than keyboard-based controls	"It would be great to [click and drag to] move the model, kind of like Google Earth" (P3)	Added 3D View mouse-based control scheme

Continued on next page

Table 4.2 – continued from previous page

Iteration	Summary of Feedback	Example	Design Improvements
3	Interest in how rotational movements could be assessed with the joint data tool.	"This looks like it would cover most types of exercises, but how would it work for something like this? [referring to a rotational exercise] (P5)"	Recorded and included Shoulder Rotation Exercise
	Participants want to have joint data values available at all times, although less objective displays may be useful.	"I feel like I would like to see a number in addition to what's displayed now." (P6)	Merged existing joint data displays to create Mixed Joint Data Display
	Standalone data is useful, but being able to compare data during or between sessions would be better	"Is there a way to compare this data to results from, say, a previous session with this patient?" (P5)	Added Sequential Joint Data Display
4	Data Display should allow sections to be toggled based on user preferences	"I can see how [the target-based display] might be useful, but I wouldn't use it much in my practice. It would be better if I could hide it." (P8)	Allowed Joint Data Display modules to be hidden/shown (options provided in system menu)
	Feedback largely positive, interest expressed in exploring in-clinic applications as well as integration with additional tools and sensors for advanced users.		

4.3.1 3D Perspective Control

As expected, physiotherapists indicated that the ability to easily view alternate perspectives was desirable. The simplified sticks-and-bones model was positively received, as it made the model easier for participants to understand in relation to

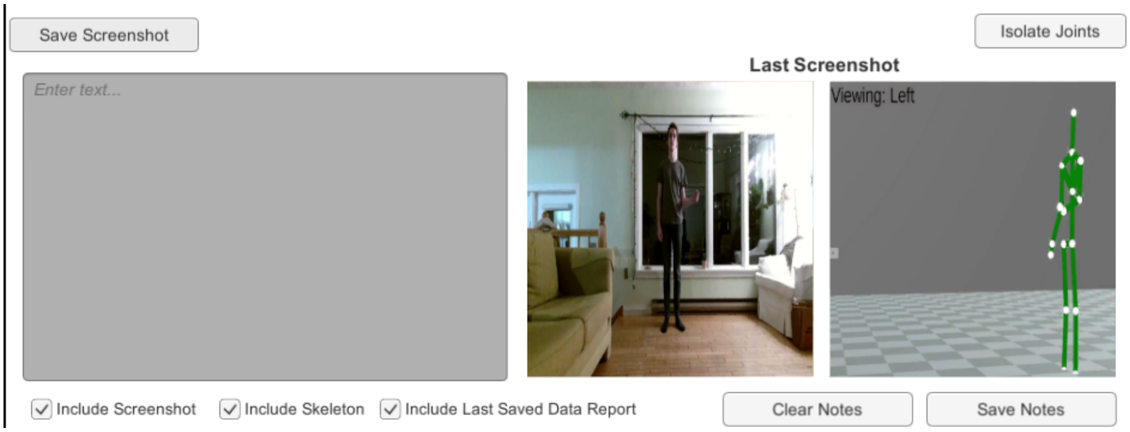


Figure 4.3: An alternate view in the final design allows physiotherapists to export notes and screenshots to another file or program.

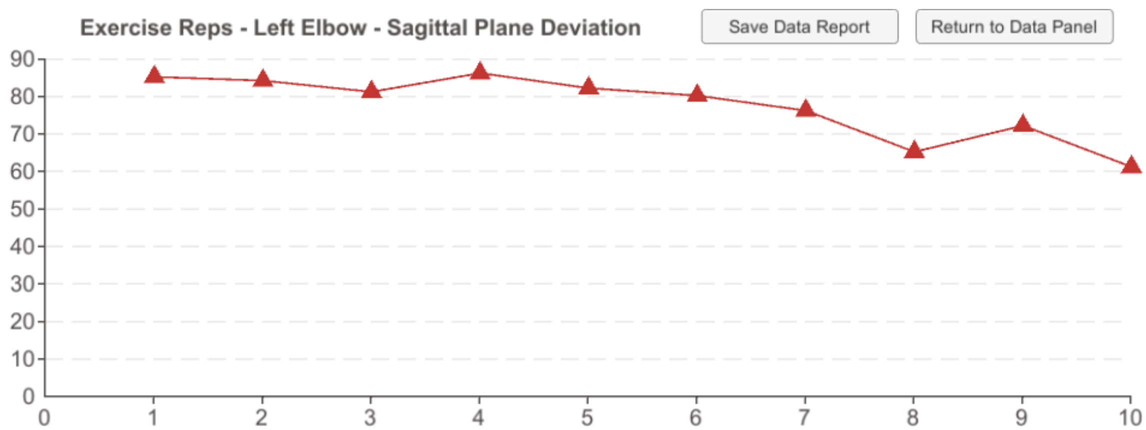


Figure 4.4: A sub-window can be enabled which displays body tracking data over several exercise repetitions.

patient movements. It was important for the patient model to be visually grounded to a floor plane, which also made it easier for users to understand the patient's position. Because the 3D view removes distracting elements and allows flexible perspective control, it serves as a suitable implementation of design goals **B1** (*Provide fixed points of reference for visual comparisons*), **B2** (*Enable standardized assessments*), and **C1** (*Reduce camerawork frequency*). We also maintained the availability of unaltered 2D patient videos in our application in an effort to support **C2** (*Preserve unmodified video display*), although this received minimal feedback from participants.

The 3D view allowed for 360 degree rotation with incremental resolution. Several

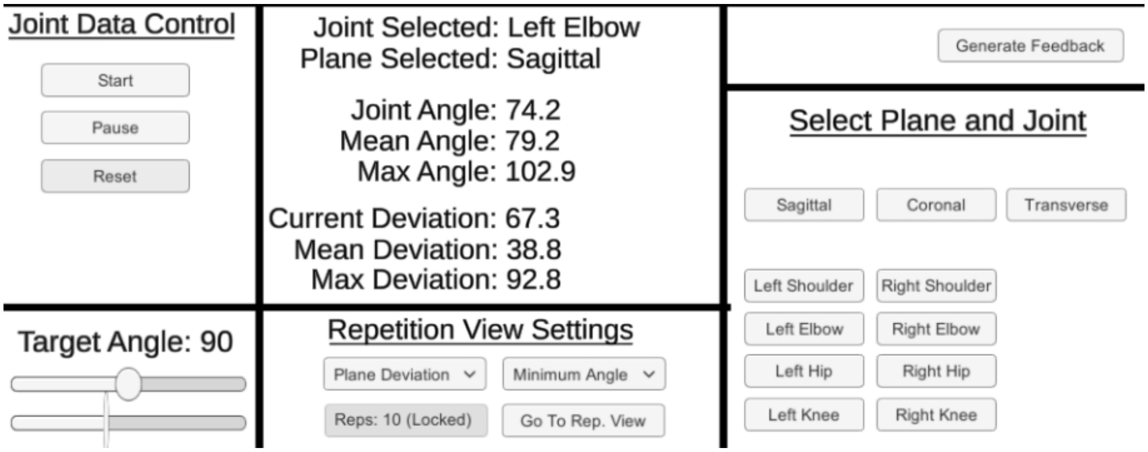


Figure 4.5: A more detailed image of the joint data display, which shows real-time data pertaining to joint movements.

participants compared this feature to familiar applications such as Google Earth. The initial keyboard-based controls were generally accepted by participants, although the mouse-based controls were seen as a more desirable option. For both control schemes, participants appreciated the ability to define their own "intermediate perspectives", not aligned with any particular anatomy or axis. When presented with alternative control schemes, which only allowed pre-defined perspectives, participants preferred the option to define their own perspectives based on the information they needed at the time, often making reference to aspects of clinical control that motivated design goal **A1** (*Facilitate control over the flow of a session*).

An early improvement was a textual marker indicating camera direction, which allowed the viewer to more easily identify which side of the patient model they were viewing (a challenge partially caused by the simple stick figure 3D model used). This would be valuable during exercise transitions, where the patient may rotate themselves to be facing a different direction, often causing the model to temporarily lose tracking in the process. Later in the design process, a "reset to front" feature allowed participants to reset the model perspective to be front-facing, which also assisted with self-orientation.

A concern going into this study was the potential impact of errors in the body-tracking solution, which could lead to noise or other inaccuracies in the patient model. While a quantitative assessment of these elements was out of scope for this study, we asked participants to comment on how accurately they felt the model represented the patient in the video. When asked by participants, we provided information about the expected error of the tracking technology used, based on existing literature [20, 23]. Overall, participants were "comfortable with [the] accuracy [of the model] in addition to the video" (P6), with several participants drawing comparisons between the visual accuracy of the model and the typical accuracy of in-person measurements and evaluations. Some participants stated that, even if these expected error ranges were comparable, they would be more confident in the body-tracking values because they were "more objective than in-person measurements" (P7). Comparing the Kinect-generated models with VNect-generated ones, participants observed differences in certain representations of joints (VNect models tended to have wider hip and shoulder representations, as well as less detailed representations of the spine). These participants expressed a general openness towards either technology, and wanted to get a further sense of how the different tracking methods aligned with different patient movements and body types.

4.3.2 Joint Data Display

In the first iteration, our implementation featured a rudimentary data display, showing the current and maximum angles for the selected joint, as depicted in figure . Over the course of the design process, a number of variations of the joint display tool were implemented for feedback. Based on participant comments, it became apparent that any such tool needed to provide precise real-time data in addition to key data points, such as the maximum joint range during an exercise. Early participants suggested an indicator-based display, which would focus on a patient's proximity to a targeted angle. However, when this type of design was presented as an option, participants preferred to view standalone numeric data instead of using target indicators. The final iteration merged these two approaches, but participants still focused on the numeric data rather than the target indicator. It's possible that because participants weren't evaluating a real patient, the ability to set a patient-specific target and evaluate a patient relative to that target was not as useful as it might be in a real physiotherapy session. Nonetheless, many participants said that they could "imagine a situation" where target-based approaches might be useful, even if these scenarios were uncommon in their practice.

P5 expressed the desire to view the changes in key data values over several repetitions of an exercise. This was implemented in our final design iteration, which allows users to select a key data value and create a line graph showing these values over time. We enabled this feature for the minimum and maximum angles, focusing on either overall joint angle or plane deviation. The generated visualization is shown separately from the real-time data display. This implementation was well-received by later participants. P7 commented that, while they appreciated the value of the real-time data display, and would occasionally observe the data values during assessments, they were more likely to incorporate the data into a session in a retroactive way, after the exercise had been performed. The graph produced by this feature could be exported into an image, for documentation purposes, or as an artifact to be provided to the patient to visualize their progress. This feature supports design goal **A2** (*Provide additional mediums for sharing information*), and could supplement other features in supporting design goals **B1** (*Provide fixed points of reference for visual comparisons*) and **B3** (*Create processes for personalized assessments*).

P3 expressed a desire to view additional data, such as the deviation of the targeted joint from an anatomical plane over the course of an exercise. The following iteration allowed users to measure a joint's deviation from either the transverse, coronal, or sagittal plane, and provided the same statistics for this deviation as were provided for overall joint angles. In addition to allowing users to obtain more data, this allows users to assess and evaluate rotational exercises that would otherwise be impossible to assess using the 3D model or the individual joint data. For example, when viewing a patient's seated hip rotation, the patient's range of motion can be measured by having them bend their knee, and monitoring the patient's deviation from the sagittal plane.

As previously mentioned with regards to the 3D model, potential errors in data collection were considered, but participants were generally confident in the accuracy of the displayed data. Participants felt that, even if some error was present, the removal of subjectivity in data collection made them more confident in the measured values. Participants also felt that an awareness of the potential error associated with different body-tracking technologies would allow them to make decisions about how to present data to patients.

4.3.3 Generating Patient Feedback

Most physiotherapists we spoke with use external tools to create exercise lists for their patients. These lists can be provided to patients as printed handouts or as digital files, and include written steps to complete the exercise as well as images or diagrams to help guide patients. These tools fall short when physiotherapists want to generate feedback during a session, or want to generate patient-specific resources. In our system, we included a way for physiotherapists to log notes during a session using the same window as the rest of the application. The ability to easily capture screenshots of the patient during a session, and to associate written feedback with those images, was well-received. Some participants compared this workflow to their in-clinic practice of taking pictures of the patient with the patient's phone, noting that "Some patients have trouble understanding the movements or understanding the feedback unless they can see themselves performing the exercise" (P4).

Our feedback tool was further improved by allowing users to select visual components to include alongside their written notes. This allows users to determine which view(s) are more useful to the patient. For example, using the 3D view, users could take several screenshots from the same perspective to enable more effective comparisons to other images. However, the 2D view can allow patients to see themselves performing an exercise, which participants identified as a valuable feature. When comparing the screenshot functionality to existing feedback generation tools, P6 remarked that "Sometimes the built-in image is busy or doesn't show things well, and we sometimes draw stick-men to simplify things. I'm terrible at drawing stick-men, so I really like being able to create a sort of stick-man from these screenshots". When the sequential data display was implemented, we allowed users to add the output from that feature to the notes generated by the feedback generation tool. The flexibility of our feedback generation tool supports design goals **B4** (*Allow flexibility in recording information*), and **A2** (*Provide additional mediums for sharing information*).

4.4 Discussion

The results of our two studies show that physiotherapists are open to new remote physiotherapy software, and are excited about the prospective benefits of our design. However, some questions remain regarding exactly how bodytracking should be implemented, and how it can be integrated with existing tools and processes. When considering TelePhysio+, several features were identified by participants as being potentially useful for in-clinic sessions, in addition to their intended use cases in remote sessions. Automatic data collection and in-session feedback generation were both notable in this regard.

By enabling real-time and retrospective displays of body-centric patient data, our design allows users to engage in more data-driven communication during physiotherapy sessions. Participants often commented on the connection between their own confidence in information, and their likelihood to share that information with patients. By providing a patient model which is less susceptible to poor camera positioning and/or video quality, in addition to providing an automatic data collection tool, our design removes or mitigates several factors which might otherwise motivate physiotherapists to withhold information from their patients. This brings attention to an added responsibility for software developers. If the perceived objectivity of the automatically collected patient data is high, physiotherapists may pass the information along to patients more willingly. This may occur even if the margin of error in collecting that information is greater than or equal to the margin of error associated with the physiotherapist's subjective interpretation of the information source.

Our primary focus in this work was to investigate the concept of perspective in remote physiotherapy. In our initial system implementation, we used a simple skeleton representation to provide a malleable 3D perspective of the patient. We hypothesized that this approach might create challenges for interpretation. However, our design process led to only minor changes to this feature, such as the addition of a indicator to facilitate understanding the model's orientation and slight adjustments to model positioning. This suggests that even simple models can be helpful for physiotherapists to effectively interpret 3D perspectives of their patients.

We also used a simplified view for displaying data in our initial implementation. In contrast to the 3D model feature, this led to friction between different users. While several participants were attracted to the rapid, instantaneous feedback from the real time data display, other participants found it distracting, and preferred to only refer to specific values after evaluating the patient using the 3D model. As additional forms of data collection were added, similar differences between participants were observed. Participants made several comments mentioning the ease of data collection using TelePhysio+, compared to their existing data collection practices during in-person sessions. When collocated, physiotherapists often rely more on secondary information (such as patient-reported pain during movements) or subjective interpretation, rather than on instrumented measurements (such as those provided by a goniometer). Some participants mentioned that they prefer assessment with less direct measurements; for example, asking the patient to reach an elevated point on a wall, and recording the height of that point as a proxy for measuring range of motion. The rationale for this was based on the availability of information and measurements in collocated settings, as well as a desire by physiotherapists to interpret the feedback provided to the patient. TelePhysio+ provides a scenario where objective data is readily available, but is provided alongside a video feed, and enables physiotherapists to interpret or withhold information as needed.

Some participants wanted to keep different types of data in separate, sparsely-populated views, while others wanted a condensed display. Other users, while appreciating that some features would be useful in other specializations, wanted to dismiss certain data views altogether. Our final iteration uses a condensed view, but the modular layout allows users to disable or enable views, which allows physiotherapists to adapt the system based on their preferences.

A potential drawback to our proposed system is the further removal of physiotherapists from their patients. We observed a trend where physiotherapists would begin assessment by observing the patient's video, before closely examining the patient's model and data. While it is reassuring that physiotherapists are drawn to information displays and automated data collection, it is possible that in a fully bilateral communication scenario (such as a remote physiotherapy session with real patients), our system will draw attention towards data displays, and therefore, draw attention away from the patient. We cannot provide conclusions in this regard; in fact, it is equally likely that the aforementioned trend is driven by a novelty effect, or is driven by existing habits among physiotherapists. However, where previous work discusses and identifies the issue of ”clinical asymmetry” in healthcare, this is an important area for future consideration and research.

More broadly, our findings can support the development of other types of videoconferencing or remote collaboration tools. Our findings around camerawork are likely applicable to other scenarios involving expert-learner communication, where reducing the need for camerawork can be a meaningful reclamation of the users' time [19]. In developing new systems for these tasks, the implementation of features as described in table 4.2 can provide insights into the types of interactions experts find valuable, even though details such as data presentation as usage may be specific to the chosen context of remote physiotherapy.

While our focus was largely on physiotherapist needs and experiences, we do not believe that patient considerations are invalidated or diminished by our findings. Previous research has established a connection between the effectiveness of clinicians, and healthcare outcomes of patients [38, 26, 28]. In both of our studies, participants often talked about ways that their strategies impact patients when working remotely. While physiotherapist-focused considerations are not sufficient to evaluate the impact of novel systems on patient care, it would be incorrect to regard physiotherapist needs as being detached from patient outcomes.

Chapter 5

Conclusion and Future Work

5.1 Future Work and Limitations

5.1.1 Integration with Existing Processes

A number of participants provided feedback on areas which were out of scope for our research, but would be important in designing a consumer-ready product. At the forefront were concerns about patient setup and installation. Reflecting on their experiences transitioning patients to remote care during the 2020 COVID-19 outbreak, participants were interested to understand the process required to install patient-facing applications that would be compatible with our design. The main concern on this topic was ease of installation for patients who may not be technologically experienced. This is an existing issue with current remote physiotherapy tools, and should be considered by software designers in the future. In the scope of our work, we only consider the patient's software as a means to provide video input to our prototype, meaning that any current tools or practices that allow video-based physiotherapy to function should also be compatible with our design.

Another concern was the integration of our design with scheduling and patient data management tools. Integration with these tools was not in scope, since standardized specifications for these features do not exist. Existing remote physiotherapy tools integrate with patient scheduling tools to allow users to keep initiate sessions and monitor upcoming sessions in the same application. Because our design focuses on exploring interactions during and after a session, this fairly trivial functionality was not a priority, and implementing such a tool would be unlikely to produce meaningful results.

One specific integration feature that was mentioned by participants was the ability to compare patient data across sessions within the tool. While this functionality is supported in our graph creation tool, and is demonstrated in figure 4.4, several other aspects of this integration were not examined in our work. Any amount of data persistence in healthcare comes with significant responsibility to maintain data security and privacy. If a physiotherapy practice were to adopt the presented design, integrating digital patient data would be an added cost and would require additional development and research in order to maintain the aforementioned principles. Presently, not all practices store this type of information in a compatible digital form.

5.1.2 Participant Diversity

While efforts were made to recruit participants from other regions in Canada, most participants were based in the Atlantic provinces of New Brunswick and Nova Scotia. In the later portions of our first study, and the entirety of our second study, these provinces had adopted heavy travel restrictions to reduce the spread of COVID-19. These restrictions kept cases low, and allowed physiotherapists to resume in-person practice with limited restrictions. This may have led to different experiences compared to physiotherapists outside of the Atlantic Canadian provinces. Furthermore, the rurality and average age demographics of these provinces may affect patient and physiotherapist concerns and considerations, and therefore the results of our studies.

Despite our efforts to recruit from a wide range of backgrounds and specializations, our recruitment method leaves open the possibility of recruiting connected, like-minded participants. Even considering the diversity present in our sample, the limited number of participants and the recruitment of colleagues and references leads to an increased likelihood of introducing community bias into our sample. This being said, our research targeted a larger sample size of physiotherapists than was achieved in other work. As more research collects and examines findings focused on physiotherapists, a comparison to our findings may reveal some biases, as well verifying and solidifying our other contributions.

5.1.3 Access to Remote Services

By implementing VNect to perform pose estimation using monocular video input, we explored a solution that seeks to be accessible to any patient with a webcam. However, our solution does not address patients without access to a webcam, or without internet access. Our participants in study 1 reported that this is uncommon, but not unheard of, and some participants had even conducted some sessions over the phone, without video. The digital divide remains an issue in rural Canada [29], and future research should consider solutions which may improve healthcare outcomes for patients without technology access.

5.1.4 Procedural Limitations

Due to the decision to perform system demonstrations and design sessions remotely, some concessions were made, particularly in the creation of exercise recordings. All recordings were performed by a researcher in good health acting in place of a patient. While some efforts were made to simulate clinically relevant problems in recordings (such as poor lighting or video quality), it would have been more accurate to use recordings of patients affected by conditions we were considering. Furthermore, while our design process ultimately led to a focus on range of motion, using actual patient recordings may have allowed us to design with more functional scenarios in mind. Physiotherapists will sometimes assess a patient based on functional activities rather than exercises, and using recordings of real patients would have enabled more insights pertaining to this scenario. Another significant concession was that participants could not interact directly with TelePhysio+. While this was necessary due to the 2020 COVID-19 pandemic, the decision to only observe indirect interactions may have influenced our findings. Notably, this means that our findings reflect the utility of TelePhysio+, but not necessarily the usability of the system.

Our work explores how physiotherapists might interact with 3D patient visualizations, but our design doesn't directly incorporate patient-facing tools. Therefore, our results don't necessarily represent physiotherapists' experiences using these systems. Some examples of work involving patient-facing systems include SleeveAR [32], YouMove[4] and Physio@Home[33]. These technologies incorporated tools to create guidance materials for patients, but these tools were not directly evaluated. Since there is very little research that focuses on physiotherapists in the remote scenarios, rather than focusing on patients, our work is an important step towards bridging the gap between physiotherapist and patient-facing tools. Further, while our work considers physiotherapist's views on touch, and on the lack thereof in remote sessions, our conclusions in this regard were similarly directed towards physiotherapists' needs, and don't consider patient expectations around physical contact in physiotherapy.

In both studies, we conducted thematic analysis. The scope of our analysis in study 2 was narrow, directed at specific software features and associated participant feedback. In study 1, our thematic analysis was much more broad, and utilized a reflexive and deductive approach to identifying needs, challenges, and opinions across our group of participants. This methodology can be incredibly flexible, and can provide high-quality findings towards the pursuit of solutions to real-world problems. However, it is possible that a deductive approach may have encoded researcher biases into the coding framework, which would in turn influence the results as data is aligned with these codes. These biases would also be reflected in the semistructured interviews that were conducted, although efforts were made to avoid leading questions that presuppose participant responses. The reflexive elements of our methodology should help anchor our findings with the data, but researcher biases must be considered alongside these findings.

More broadly, our work does not examine patient-physiotherapist communication (as a 2-sided interaction) using our remote physiotherapy system. Examining both sides of this interaction is an important area for future research, both as a means to further evaluate our presented system, and as a way to expand on the existing body of telehealth research in a more physiotherapy-focused manner. Both our work and existing literature have identified bodily communication as a key component of patient-physiotherapist communication, which may lead to differences compared to more broadly-scoped telehealth and medical communication research [3].

5.1.5 Technological Limitations

While 3D pose estimation technology is promising, some work remains to be done in supporting the wide range of exercises used in physiotherapy. In selecting exercises for the second study, we found a number of floor-based poses were impossible to resolve using the two implemented body-tracking methods. An example of an exercise which was excluded was a static hip flexor exercise where the patient folds one leg in front of them with the other leg stretched behind them, with the torso remaining upright. We found that neither the Kinect nor the VNect models we implemented were capable of resolving this posture from any angle. Accurately recording this exercise would have helped us explore postures and movements which were more complex and difficult to understand remotely.

In the case of VNect, which uses machine learning, this is likely to be a combination of increased limb occlusion and a lack of representative postures in the model's training dataset. Furthermore, our demonstration only feature a single actor, which is only representative of that actor's body type. We suggest that a pose estimation dataset, featuring a diverse range of body types and directed towards physiotherapy exercises and postures, would be a valuable contribution to research in this domain, and would likely be required to produce a consumer-ready product.

5.2 Conclusion

System design studies focusing on the needs and expectations of physiotherapists in remote scenarios are uncommon. Through our research, we found that critical design goals for physiotherapist-facing systems are; overcoming lack of touch through improved information-gathering tools, providing (technology-)integrated means of measuring progress, and reducing the need for camerawork on behalf of the patient. These goals are supported by semi-structured interviews with 7 physiotherapists, and were implemented in our participatory design study involving 8 physiotherapists. Our research captures perspectives from participants with a diverse range of specializations and remote physiotherapy experience. We go on to discuss areas where our design meets physiotherapist expectations, as well as areas where additional development could further improve physiotherapist and patient experiences.

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Appendix A

Thematic Analysis Codebook

A.1 Final Codebook Iteration

```
Thematic Analysis Codebook V4


Touch
  Touch.Outcomes
    - Reasons to use hands-on treatment, or to touch the
patient's body
    - Outcomes of using manual therapy/hands-on treatment
  Touch.Perceptions
    - Perceptions of touch as part of physiotherapy
  Touch.Barriers
    - What can/cannot be done without touch?
  Touch.Other
    - Anything related to touch that doesn't fit in the
above categories
Technology
```

Technology.Perceptions

Technology.Perceptions.Patient

- Patient perceptions of Technology
- My patients don't really use technology and have trouble with the software
- My patients are uncomfortable with remote physio software for privacy reasons (ie Zoom issues w/ privacy)
- My patients are tech-savvy and like using their phone for remote physio

Technology.Perceptions.Physiotherapist

- Physiotherapist perceptions of technology
- "I don't really use technology and have trouble with the software"
- "I am uncomfortable using technology I haven't been trained on"
- "I get a lot of use out of the screenshot feature on my iPad when working with patients"

Technology.Features

- Features/setups used for remote physio. Note that there are also codes for camera/spatial stuff. Those could also be coded here, but because those areas are likely to be very dense, I split them off into their own codes.

Technology.Features.Hardware

- "Most of my patients use a laptop or their phone"
- "I had to buy a wireless headset for remote physio"

Technology.Features.Software

- Chat to send resources during telehealth
- Videoconferencing/booking software

```
  Technology.Clinic

    - Aspects of technology used for in-person sessions

    - May overlap with modalities

  Technology.Intersession

    - Technology used for in between sessions

    - Email as a communciation tool

    - Sending videos to patients

    - Databases for sending handouts


Camera

  Camera.Perspective

    - Issues with angling/positioning the camera

  Camera.Lighting

    - Concerns about lighting

  Camera.FOV

    - Field of view issues

  Camera.Details

    - Problems seeing smaller details, or with low
resolution
  Camera.Other


Environment

  Environment.Patient

    -"The patient usually didn't have the space to
perform some exercises"
  Environment.Physiotherapist

    -"I had to rearrange my furniture during sessions"
```

-"I was able to use my clinic to do remote sessions, so I had lots of space"

Time

- "I have more time with each patient when working remotely"
- "It takes a long time for patients to commute to a clinic"
- "I'm more flexible with my hours while working remotely"
- "I respond to emails after-hours, even when not working remotely"
- flow of remote sessions, managing time during sessions

HealthConcerns

- Mostly COVID, but other concerns will potentially show up here and can be classified as COVID/non-COVID
- Concerns around transmission of disease/re-opening

Training

- "I am uncomfortable using technology I haven't been trained on"
- "Remote physio is nothing like what I learned in school"
- Other aspects of physio training/education that get discussed

Patient

Patient.Conditions

- Stroke, Injury, Aging
- Condition-specific practices and considerations

```
  Patient.Characteristics
    - Age, Atheleticism, Gender, etc.
    - "A lot of my patients have kids and need to manage
them during sessions"
    - "This is better for younger patients"
  Patient.Goals
    - Motivation for seeking PT treatment
    - What type of progress matters to the patient?
  Patient.Adherence
    - Exercises the patient performs on their own time (
not in sessions)
    - Things the patient does to prepare for PT
    - Patient tendency to perform home exercises
    - Tracking out-of-clinic exercises

Physiotherapy
  Physiotherapy.Profession
    - Thoughts on the profession, or on conventional
practices
    - Habits among PTs
    - References to "we" as in "physiotherapists", or to
"lots of practices/companies do this"
  Physiotherapy.Practices
    - Structures and systems motivating certain practices
    - "We use this test because it's standardized and
helps with insurance"
    - "We use subjective measurements because..."
    - Protocols, Insurance
```

```
Telehealth

  Telehealth.Perceptions

    - Perceptions of technology specifically related in
telehealth/remote physio
    - "I don't like telehealth because of the physical
seperation from my patients"
    - "This telehealth app is nice because..."

  Telehealth.Integration

    - How much of PT should be telehealth?

    - What factors determine when telehalth should be
used?
    - Compartmentalizing/establishing boundaries

      - This can be done remote, this cannot, minimal
overlap between remote and in-person physio work
        - Different from distinguishing what works/doesn'
t work well remotely, this should come from PT
experiences doing remote physio
      - Remote aspects that are integrated with regular
in-person appts.
      - Rules for patient access (email, chat, etc.), "
when can the patient contact you with their questions" (
right to disconnect literature re: WFH)
  Telehealth.Comparisons

    - What PT elements are better for telehealth? What is
 not good for telehealth?


Exercises

  - Exercises.Tools

    - Weights, bands, other equipment used for exercises
```

```
    - Tools used to measure progress (goniometer, etc)
  - Exercises.Resources
    - Handouts, videos, other supplements to guidance
    - annotation, taking pictures or video
  - Exercises.Communication
    - 1-on-1 vs group physio
    - How do PTs guide patients?
    - Observations from PTs about the way they do
guidance
  - Exercises.Assessment
    - What do PTs measure and how?
    - Setting/defining goals
    - Measuring patient progress
  - Exercises.Modalities
    - Modalities that are used in treatment
  - Exercises.General
    - Tag unique exercises here
  - Exercises.Corrections
    - Common patient mistakes and ways that PTs correct
them

Other
  - Anything that might be important/interesting, but
doesn't really fit anywhere else (this code should have
no overlap)
  - lapses in continuum of care (transfer of medical info
 to/from PT)
  - Patient misconceptions about their condition
```

Demo

  - For organization and context, use this code in addition to other codes we identify that are related to the prototype demo we show participants
  - Generally in the last couple minutes of the transcripts

------===Changelog===---

Version 2

-> Reworked codes into hierarchy structure

Version 3

-> Added Demo code

-> Merged Touch.Reasons and Touch.Effects into Touch.Outcomes

-> Added Touch.Barriers

  -> Some Touch.Perceptions stuff will be better coded as this.

-> Changed distinction between Physiotherapy.Motivations, Physiotherapy.Goals, Patient.Goals

  -> Patient.Goals is for goals that matter to ther patient ie. being able to golf properly

  -> Physiotherapy.Motivations is renamed to Physiotherapy.Practices, and refers to professional structures that are established and used in their work.

```
  -> Physiotherapy.Goals is moved to Exercises.Assessment
, and refers to things the participant uses to track
progress and measure outcomes.
-> Pulled Technology.Perceptions.Telehealth into
Telehealth.Perceptions
-> Pulled Comparisons into Telehealth.Comparisons
-> Added Telehealth.Integration
  -> Integration was missed in previous versions.
-> Added Exercises and related subcodes
  -> Exercises.Tools covers a gap in our previous
codebook
  -> Exercises.Resources/Communication covers aspects of
Communication Dynamics, which was previously included
under Other.
-> Moved boundaries section from Other to Telehealth.
Integration
  -> This hasn't really come up in interviews yet but if
it does, it fits better here.
-> Added clarification for codes based on discussion



Version 4
-> Added Exercises.General for coding different types of
exercises
-> Added Exercises.Corrections for coding types of errors
 and corrections used by PTs
-> Added Technology.Network for coding internet
connection/access stuff
-> Added Exercises.Modalities for coding different
modalities used in-clinic
```

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