Towards Next-Generation Remote Physiotherapy with Videoconferencing Tools

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ABSTRACT
Many common injuries can be treated effectively with physiotherapy, but getting access to this treatment is difficult for those living in remote or rural locations. To help formulate design requirements for next-generation tools for supporting remote physiotherapy (i.e. telerehabilitation), we conducted design sessions with five practicing physiotherapists. We developed three technology probes as prompts for these discussions, helping us to gain an understanding of physiotherapists’ activities and communication practices. Our analysis shows that telerehabilitation tools should be specifically designed to address communication and work in relation to clients’ physical bodies, and that visual communication can be enhanced through augmentation to videoconferencing tools and accessible hardware to account for a lack of tactile communication.

INTRODUCTION
For many injuries and movement disorders, physical therapy (physiotherapy), can decrease disability and increase function of affected body parts [26]. Everyday occupational hazards and repetitive movements bring on such injuries; for example, rotator cuff tendinitis is brought on by frequent overhead reaching (for window washers and painters). In order to rehabilitate the affected joint, a physiotherapist would guide a patient through (and assign as homework) exercises such as in Figure 1.

While physiotherapy is extremely effective, it remains inaccessible to a large portion of the population. In Canada, most physiotherapists (>90%) work in urban centers [6]; whereas over 18% of the population live in rural areas [22]. Many of these people living in rural areas have jobs that require manual labour, and under these conditions sustain injuries that can be addressed through physiotherapy—but getting access to these services is a challenge. A practicing physiotherapist with whom we spoke best articulates this problem: “They’re so far away from an actual physiotherapist. The problem is that just driving into the city takes them four hours—each way—and that makes the problem even worse!”

Our goal is to design technologies for remote physiotherapy that respect communication practices used by physiotherapists. The problem is that we do not understand the nature of communication between physiotherapist and patient. A further constraint is to understand what effective treatment might look like when delivered only through readily available tools in the immediate term—specifically, we see video conferencing (perhaps augmented with high resolution cameras or depth cameras) as the main practical solution in the near term.

Our approach to this problem was to develop three simple technology probes [8], and to use these probes in several design sessions with five practicing physiotherapists. Our probes addressed our initial intuitions about characteristics of physiotherapy practice, including the role of mirrors, discussion, and home exercise. We used the probes as prompts to understand current practices, worked with the physiotherapists in mock treatment, and discussed alternate designs to support remote physiotherapy.

Our findings provide a nuanced understanding of both the activities physiotherapists need to support (given the limitations of technology), and design considerations to address these activities remotely. For instance, given hands-on instruction is impossible in a remote context, the physiotherapist must have other tools at her disposal to address this shortcoming. We demonstrate that an emphasis

![Figure 1. Patient performing an external rotation exercise, using a resistance band. The patient starts by holding the resistance band across his chest, and rotates his forearm away from his body against the band’s resistance.](image)

on the body and its environment as a workspace is necessary to facilitate remote physiotherapy, and that much of this can be accomplished by augmenting video conferencing.

We make two contributions in this work. First, we provide insights into a specific domain (physiotherapy) that can be used to guide design of future video communication technologies. Second, from this work, we explore the concept of the body as a workspace, developing this idea through both technology probes and discussion. Our ongoing work involves designing tools for effective remote physiotherapy, though the findings should also support other domains where it is important to remotely teach activities that require specific movements.

**Physiotherapy Process**

To set the scene, we first provide a nominal account of the physiotherapy process—this will help provide context for our description of both related work and our problem space. This account comes from both our own experience (as physiotherapy clients), as well as from our discussions with the practicing physiotherapists.

Physiotherapists work with most patients through three phases of treatment: assessment, at-home exercise, and follow-up. Activities in these phases include teaching the patient exercises and correcting improper motions through movement guidance, as well as constantly performing assessments, since the physiotherapist must take measurements related to disability and function to create an effective treatment plan. In the rotator cuff tendinitis example, which we will revisit throughout this paper, the physical therapist might measure how high her patient can raise his arm. The patient also performs exercises between sessions to build strength and/or flexibility. Assessment and movement guidance may require hands-on interaction, which requires collocation of the physiotherapist and patient. Follow-up sessions comprise exercise (performing exercises such as in Figure 1), manual therapy (e.g. the physiotherapist physically massages the shoulder), and discussions about home-treatment (e.g. applying ice or heat to the shoulder). Each appointment and case is very personalized, customized for the patient’s injury, body shape, etc.

**RELATED WORK**

Remote physiotherapy fits within the space of three related areas: telerehabilitation, technology to support traditional physical therapy, and remote workspace tools from the CSCW community.

**Telerehabilitation**

*Effectiveness of Treatment.* While work in telerehabilitation is still in its infancy, early pilot studies show promising objective and subjective results [11, 17, 26], with joint replacement and stroke therapy being common conditions for study [16]. Much of this pilot work employs considerable technology (e.g. sensors, haptics, and even virtual reality technologies) that is readily available in research labs, but far less likely to appear in patients' homes. Nevertheless, studies exploring the use of videoconferencing-based telerehabilitation following total knee replacement report positive results [17, 26]. For stroke rehabilitation, a community-based approach using videoconferencing tools demonstrated that patients showed significant improvement in all treatment measures, with additional mental and social benefits of group physical therapy [11]. Furthermore, there seem to be high satisfaction levels for both patients and physiotherapists in spite of the lack of face-to-face time [25].

*Remote Assessment.* Given the central role of assessment in physiotherapy, what are the limitations of conducting assessment remotely? In general, the literature suggests that assessments involving coarse-grained detail, such as gross movement or patient environment, are well suited for remote assessment [4, 19]. However, in cases where physiotherapists must use touch, e.g. feeling to check whether a joint is moving properly, remote assessment is not possible. There may also be trade-offs in terms of satisfaction: a study of PhysioDirect, a phone service connecting patients to physiotherapists for an initial assessment and advice, found that while the service was clinically effective, reduced delays in treatment advice, and seemed to be safe, patients were less satisfied compared to face-to-face treatment [18]. On the other hand, video into the home may actually provide other benefits, and the patient’s living environment may be assessed remotely using videoconferencing tools [19], important since complete assessment also involves understanding the patient’s entire living environment.

**Tools to Support Traditional Physiotherapy**

Development of both commercial and research tools for physiotherapy provide insight into some basic issues that we build on in our work.

*Assessment.* To address inaccurate measurement and progress tracking, Nicolau et al. employ a motion-tracking system, which lets the physiotherapist save motions for later playback, rotate the view of the visualization, and overlay a movement onto a previous one for comparison [14]. DartFish, a commercial video analysis tool commonly used in sports training [7], provides video analysis tools that have been used to support the assessment of gait disorders [2]. Useful features of these systems, such as progress tracking and angle measurement, may be considered when designing technology for telerehabilitation assessment.

*Motivation and Proper Exercises.* Prescribed at-home exercise can help patients improve range of motion and reduce pain, but patients frequently do not perform

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1 For consistency, we refer to the physiotherapist as female and patient as male.
exercises as recommended [5]. Frustration and lack of motivation often lead to non-compliance, and certain tools have attempted to make the process of exercising more engaging and enjoyable. Kinererehab makes use of audio and video feedback to engage patients in entertaining rehabilitation [5]. The game-like nature of commercial video capture virtual reality systems such as the Sony EyeToy and VividGroup’s GX system may provide effective motivation for some patients, but the utility of these may be limited as physiotherapists cannot customize the games to their patients’ needs [28].

Movement Guidance. Some recent research has explored teaching or guiding users through movements, and applications using ideas from such systems will likely prove useful for at-home exercise between sessions without the therapists. For example, LightGuide projects a movement guide onto the user’s skin, and guides the user in through specific, fine-grained motions using feedback and feedforward cues [21]; the specific approach may be somewhat limited though, as it emphasizes body parts that are visible. MotionMA provides visual feedback based on models of body and movement to guide a user in exercises [27], though this specific approach provides very coarse-grained feedback, instructing the user to translate one or two bones of interest vertically or horizontally. Nike+ Kinect provides a virtual avatar that demonstrates exercises, and by sensing the user’s actions through the Kinect, provides verbal corrections to correct movement [15]. Similar to MotionMA, this is feedback is limited by the sensing technology (depth sensor), and the feedback is insufficiently too coarse-grained (at this point) for most physiotherapy exercises.

Teaching Skills with CSCW Systems
Several CSCW systems have explored supporting non-verbal activity for group work over remote surfaces, including gestures, and eye contact [9, 24]. These have been demonstrated to help teaching activities since they provide for additional cues beyond verbal description. For example, VideoDraw provides a view of a remote collaborator’s gestures over a shared workspace [24]. These gestures were emphasized in a study of TeamWorkstation-2, where calligraphy was taught to remote students, allowing both to see gesture and drawing simultaneously [9]. ClearBoard employed a “working with a collaborator through a pane of glass” metaphor, allowing a teacher to not only communicate with gesture, but also to monitor the student’s gaze to ensure they were focusing on the proper space of the game board. Similarly, MirrorFugue, a tool to support remote piano instruction, explored the use of projection of an instructor’s hands onto the student’s piano in various orientations to find out where the representation of the hands was most effective for communication [29].

While these systems emphasized gesture and communication over a shared flat surface (such as a table) as a workspace, a physiotherapist’s workspace is the patient’s body, and the space surrounding it. In spite of this fundamental change, we sought to take these lessons about the role of non-verbal communication (gesture, gaze, annotation, and collaborator representation) into this new domain to support assessment and teaching of dynamic movement instruction in physiotherapy.

TECHNOLOGY PROBES
We took a technology probe approach to this problem, developing three simple probes to articulate our intuitions, and to stimulate discussion with physiotherapists. The technology probe approach argues for the design of simple, fully functional tools (with only one feature) to challenge and inspire researchers and domain experts [8]. Given that most physiotherapists only work in collocated scenarios, we chose this approach, as it allowed the physiotherapists to imagine concretely what remote physiotherapy practice might be like. Specifically, our probes allowed us to challenge conventional videoconferencing technologies, and served as prompts for discussion.

Based on informal discussions with physiotherapists (and our own experiences as physiotherapy clients), we developed three probes to explore remote physiotherapy: a mirror videoconferencing system, where the physiotherapist and patient are represented as if they were in a mirror together, an annotation system that allows physical therapists to draw on and around the body of the patient, and a targeting system that allows a physiotherapist to define a path of targets for the patient to move through. Thematically, we drew on ideas from CSCW, addressing the fact that physiotherapists would not have the ability to make use of their hands in treatment, though still needing a means to gesture, discuss and refer to the patient’s body.

These probes were built using an commodity depth camera—an inexpensive device that would be present in many homes. To facilitate discussion with physiotherapists, we built a paired videoconferencing environment in our lab, to mimic a real-life setup.

Probe 1: Mirror for Shared Discussion
Figure 2 illustrates the first technology probe, a videoconferencing environment where each participant is made to feel like they are sharing a mirror with remote participants (akin to HyperMirror [13]). Since we used depth cameras for this prototype, we are also able to respect the depth relationships between participants as illustrated in Figures 2 and 3 [12]. We based this probe on our experience in a real physiotherapist’s office, where the physiotherapist stands with the patient in a mirror in order to show/teach exercises. Communication occurs through the mirror, where the physiotherapist can demonstrate an exercise alongside a patient’s attempt, while allowing the physiotherapist to gesture at parts of the patient’s body if it is not moving or positioned correctly. Figure 3 illustrates the view from the client’s perspective. We also built a standard video-conferencing prototype, with the remote
participant filling the display and the local participant inset in the corner of the same display, to allow therapists to compare the experience using the same camera and display as the mirror probe.

**Probe 2: Annotation of Bodyspace**

Our second probe focused on providing therapists with a means to annotate the patient’s body and the area around it. As Figure 4 illustrates, the tablet-based system is built atop the first probe, and provides the therapist (and potentially the patient) with a view of the video scene that can be paused and drawn on (drawing on the live video is also permitted). This would, in principle, allow the therapist use the annotations to complement discussion about a body part or movement—different colours and brush sizes allow for expressivity in these annotations (e.g. for different muscle groups). The pausing feature is important, as the patient’s body is frequently in-motion, and so annotations to the live video can quickly become out of sync with the patient’s actual body. Furthermore, the annotations might be of body parts that are not visible to the patient (e.g. if he has injured his back).

**Probe 3: Target Paths for Movement**

The third probe allowed the physiotherapist to define a path in space (through a set of targets), where the patient could later “retrace” that path for exercise (Figure 5). Here, we drew on themes from prior work emphasizing notion of feedforward and feedback in guiding movement through space. The targets are represented in 3D space (i.e. within the limitations of the sensing technology), with the size of the target representing its relative depth in the scene. The therapist places targets by physically moving her own limbs in space, and communicating with the system through voice commands. Once the therapist has placed the targets, the patient can then perform exercises by correctly moving through the targets, with visual feedback given if the target has been reached (Figure 5, middle and right). For simplicity, the probe itself focused on movement only in the right hand.

**SESSIONS WITH PHYSIOTHERAPISTS**

The five physiotherapists that we worked with participated separately in sessions that were structured around the technology. These sessions consisted of interviews about their practice, observation of their use of the technology probes in mock sessions, and discussions about their experiences with the probes. In some cases, where physical therapists could not actually make use of the probes, we had them watch video of the probe in use and discussed their reactions to the technology.

We had three goals in the sessions: (1) to understand communication practices of physiotherapists when working with patients; (2) to compare our video-conferencing approach (in probe 1) to a conventional videoconferencing approach, and (3) to understand whether/how our probes addressed their perceived communication needs in a remote
physiotherapy scenario. Early sessions focused only on the mirror probe, and these discussions led to subsequent probes. The sessions were loosely structured, allowing the impressions of the probes, as well as the interactions in mock treatment, to guide the questions and discussions.

Our participants were actively practicing physiotherapists, and recruited through word of mouth. As detailed in Table 1, some physiotherapists made repeat visits as we continued to develop probes to further our inquiry.

**FINDINGS**

From our discussions with the physiotherapists, we distill three major categories of activity (movement guidance, assessment, and exercise between sessions), and three main forms of communication with patients. While there are additional activities that physiotherapists engage in, we found through our work with participating physiotherapists that these were the most pressing in terms of designing viable technology for remote physiotherapy:

- **Movement guidance**: Physiotherapists guide patients in performing exercises that help strengthen or increase flexibility. Proper form is important.
- **Assessment**: Physical therapists diagnose conditions and guide a patient’s treatment through subjective and objective measurement of certain variables.
- **Exercise between sessions**: Patients continue work while separated from the physical therapist between sessions by performing exercises as directed by the physical therapist.

From observations of physiotherapists in mock treatment, as well as their verbal descriptions of practice, we identified three main methods for communication within these physiotherapy activities:

- **Tactile**: Physical therapists use their hands for assessment and to guide motions. This may involve touching patients, putting their hands on the patient to prevent movement, or to induce movement.
- **Verbal**: Physiotherapists also give verbal instructions for motion, as well as ask questions and receive verbal responses from patients.
- **Visual**: Physical therapists demonstrate proper exercises to patients, and also visually guide the patient using gestures. We focus on increasing the capacity for visual communication to account for a lack of tactile interaction in telerehabilitation.

We next discuss each activity in turn, describing current practices in traditional physiotherapy, before turning to insights gained from discussion with physiotherapists about how each could be supported through telerehabilitation.

**Movement Guidance**

**Tactile.** While working to guide the patient in an exercise during collocated therapy, the physiotherapist makes use of her hands to manipulate specific body parts for proper form. In our external rotation example, the physical therapist may physically guide the patient’s elbow into his side with her hand if he is holding the elbow too far out. While it is common for the physiotherapist to use her hands for guidance, this is only used after other communication techniques have been exhausted and the patient does not understand the instruction. This is a last resort when correcting exercise movements, because physiotherapists want to see what the patient can do on his own, since the physical therapist will not be with the patient while they are doing exercises at home between sessions.

**Verbal.** In collocated therapy, the physiotherapist often tells the patient how she wants him to move, using verbal instructions. This is usually combined with visual or tactile information, and the physical therapist might say something like “tuck your elbow in” while demonstrating the motion or physically guiding the patient’s elbow into his side for an external rotation exercise. While description is often paired with other tactics, it may be used on its own. An example of this is the physiotherapist verbally instructing the patient to slow down or speed up a movement.

**Visual.** Physiotherapists communicate with patients using visual information in two ways: first, through demonstration, and second through gesture. The physical therapist usually demonstrates the proper exercise to the patient so that he can see the entire form. Physiotherapists will also use gesture, pointing at various body parts to indicate what should stay still, what should move, and how far. For example, in the external rotation exercise, the physiotherapist will show the patient the motion, and if he fails to keep his elbow tucked in to his side, the physical therapist might point at the elbow and ask him to keep it closer to his body.

Physiotherapy often takes place in front of a mirror, which makes it easier for a patient to see and understand how his body is positioned and how he moves. To this end, the mirror helps to train the patient’s proprioceptive sense, or his awareness of his body’s position in space [23]. Beyond this, placing the patient next to the physical therapist in a mirror image (as in the mirror probe), allows the patient to easily model the ideal version of an exercise, which is a way that people learn to recreate movements [20]. In collocated treatment, the physiotherapist can mark up the

<table>
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<th>Physio #</th>
<th>Sessions</th>
<th>Gender</th>
<th>Experience (years)</th>
<th>Probes</th>
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<td>M</td>
<td>3</td>
<td>Mirror</td>
<td>Orthopedic</td>
</tr>
<tr>
<td>P2</td>
<td>2</td>
<td>F</td>
<td>1</td>
<td>Mirror, Targeting</td>
<td>Orthopedic</td>
</tr>
<tr>
<td>P3</td>
<td>2</td>
<td>F</td>
<td>5</td>
<td>Mirror, Targeting, Geriatric Annotation</td>
<td></td>
</tr>
<tr>
<td>P4</td>
<td>1</td>
<td>F</td>
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</tr>
<tr>
<td>P5</td>
<td>1</td>
<td>F</td>
<td>15</td>
<td>Mirror, Targeting, Orthopedic Annotation</td>
<td></td>
</tr>
</tbody>
</table>

**Table 1. Physiotherapist participants.**
mirror to better train proprioceptive senses. One of our participants noted:

[The patient] might feel straight, and then you put a piece of tape down a mirror and say, ‘Line yourself up with that tape’, and that might feel really odd, but now we’re training them proprioceptively. They’re getting visual feedback so they know that they’re lined up, even if they don’t feel like they are. – [P4]

Conventional videoconferencing technologies do not provide good support for providing a patient with a view of himself, nor for the physiotherapist to meaningfully help guide motion. To this end, the mirror and annotation probes worked extremely well for the therapists. Not only could the patients again see themselves while performing the movements (thereby helping to train proprioception), the mirror itself provides visual feedback. Furthermore, placing the physiotherapist also into the mirror allowed them to make intuitive gestures that they commonly use in collocated therapy to guide the patient (Figure 3). The annotation probe was thought to be better for general movement guidance such as drawing on a joint to help the patient keep it from moving. Finally, physiotherapists working with the targeting probe saw potential to support movements for stroke therapy, since this type of therapy already involves working with targets. Thus, the targets would provide both additional feedback (for movement) as well as posture feedback, provided by the mirror probe.

The single camera and display setup did not allow the patient to see certain parts of his body while performing some exercises, but the pause feature of the annotation probe allowed the patient to perform an exercise facing away from the camera, the physiotherapist to pause the video, and the patient to turn to view instructions as the physiotherapist annotated on the paused screen.

Assessment

Tactile. In collocated treatment, physiotherapists receive certain types of information using touch, and this tactile interaction lets the physical therapist “read” information from the patient with her hands. A common assessment in rehabilitation is strength. In the external rotation example, the physiotherapist might put a certain amount of resistance on the forearm while the patient attempts to rotate, and the physical therapist can gauge strength based on the amount of force the patient applies against the physiotherapist’s resistance. The physiotherapist might also use touch to feel how muscles are firing, check skin temperature, or feel to check whether a joint is stuck and not moving properly.

Verbal. While assessing the patient’s abilities, the physical therapist will ask the patient questions about pain, medical history, or lifestyle, and will receive verbal responses. An example of this in the external rotation would be the physiotherapist asking if the patient has pain or discomfort in the exercise, and the patient responding with a number on a scale from one to ten.

A conventional videoconferencing system will facilitate conversation; however, because a physiotherapist cannot touch the patient, assessment would require more active involvement from the patient. The physical therapist can guide the patient in obtaining measurements like blood pressure, heart rate and circumference around a limb using a tape measure, with the patient conveying this information to the physiotherapist verbally [4], but this would require additional work, and potentially tools.

Visual. Visual inspection is used as a method for assessing the patient in many ways. For example, the patient might demonstrate his ability to perform an exercise for the physiotherapist to assess the motion, and she may check things like skin tone, scar characteristics, and hair growth, visually. Physiotherapists also assess range of motion by measuring the angle of rotation at a joint, either strictly visually or with a tool called a goniometer, which is similar to a protractor.

The physical therapist is not only concerned about how the patient moves, but is constantly visually reading the patient for “soft signals”:

[Discomfort and pain] are some of the soft signals that you pick up on. You can kind of see that recoil, you can see their expression change. So if there’s any area that I would make sure I try not to sacrifice the picture, it would be the face. [P3]

These subtle signals convey non-verbal information to the physiotherapist, such as pain or discomfort levels, and the physical therapist also watches expressions when teaching exercises to make sure the patient understands the instructions. Since videoconferencing technologies typically suffer from fidelity issues, it is important that image quality allows physiotherapists to read a patient’s facial expressions whenever necessary. This may become an issue if the patient’s face is turned away from the camera when performing an exercise.

To support rehabilitation, still images or higher quality store-and-forward video is used to address resolution problems in some cases [4]. For range of motion assessment, our participants felt that being able to actively display joint angle information for patients would be valuable, though they were concerned about accuracy and points of interest in angle measurements for reliability.

The targeting probe would be useful for assessment of movement for stroke therapy, but the path of the patient’s movement between targets is important for physiotherapists to see, so high resolution and frame rate are important in telerehabilitation tools for stroke. Stroke patients may use the physiotherapist’s finger as a target to touch in collocated therapy, with the touch sensation providing feedback of a successful interaction. Accordingly, target color change provided reasonable feedback in the absence of touch.
While we initially thought the annotation probe would be used strictly for movement guidance, the physiotherapists saw it as a useful tool for tracking progress. With consistent patient placement through calibration, range of motion could be assessed by marking the extent of the rotation on the screen, and saving a screenshot for future reference and comparison. This serves as a visual charting tool for the physical therapist, but also as a motivational tool for the patient.

Nevertheless, our physiotherapists expressed concern that they might not feel confident about assessments in many cases given that they could not touch and feel the patients. Some of this concern comes from the inability to employ tools (even their own hands) for accurate or reliable measurement.

**Exercising Between Sessions**

Between treatment sessions, the physiotherapist often provides her patient with exercises that he can do on his own to improve his condition. It is important that the patient performs these exercises regularly and correctly, so physiotherapists usually provide patients handouts with images and descriptions of how to perform the exercises. Physical therapists might also provide the patient with a video recording of the prescribed exercises, which should result in better understanding and execution of exercises by patients [10]. Since these instructional aids are generic, they can be difficult to use for those patients that have special needs, such as a broken limb, and require customization to their exercises.

*Verbal.* Conventional physical therapy exercises between sessions make use of description through either spoken or written words. If the patient is using a pamphlet for exercises, it conveys information through text, instructing the patient on how to move with words that accompany diagrams. If the patient is given a video recording, the physiotherapist can record verbal descriptions of the exercises, or the model in the video can describe the motions.

*Visual.* Two types of visual information may be communicated during solo exercises between sessions, depending on the method used by the physiotherapist. If a handout is used, the visual consists of a photograph or illustration of a person performing the exercises over a few different frames. If a video is used, the visual is the recorded image of a person actually performing the exercise. Though not as effective as a video, most physical therapists provide only a paper handout with an illustration and description of the exercise.

The most apparent problem with exercising at home between sessions is the lack of guidance for the patient. Even through videos provide a dynamic representation of the exercise in real-time, patients may not be able to recreate the exercise properly in practice. The patient may think he is moving in the same way as the model, but proprioceptive difficulties and viewing angle problems may mislead the patient. This issue is made worse when the patient has a special consideration that requires the exercise to be modified in some way, complicating the reproduction of the movement.

All of our participants felt that, though most do not use it in practice, some kind of video recording would be better than the handouts they currently use. Allowing the physiotherapist to record the patient while he is performing the proper exercise to play back using the mirror probe should be more effective than a regular video, because the patient can see himself beside the model with his likeness, and might prompt better muscle memory. Since the mirror probe uses depth, the patient could even step inside his former representation to try to match the movement [1].

Our physiotherapists agreed that an important feature to include for exercising at home between sessions would be some kind of guidance, similar to what commercial tools attempt to provide, e.g. the virtual instructor providing live verbal movement corrections to the player in Nike+ Kinect [15]:

*I think some of the [games] that show how well you mirror [the exercise] might be really valuable. You could look at how close you could mirror the person’s motion. It will show up as a line if you aren’t matching the person on screen.* [P5]

The targeting probe would be useful for stroke rehabilitation between sessions, since it already involves a lot of repetitive motion, but current practice generally does not provide the patient with interactive targets, which are useful. While the annotation probe was not discussed in-depth for exercising between sessions, the suggestion was made that a kind of combination of the annotation and targeting probes might be useful. Being able to draw a path for the patient to follow, and providing feedback when they are not following correctly, would be useful for a patient working solo and starts to deliver some kind of automatic correction.

Our physiotherapists also thought that recording these “at home” sessions would be useful for later perusal by physiotherapists: both to ensure adherence to the exercise plan, and also to ensure that the exercises were being performed correctly.

**DISCUSSION**

**Exercising at Home without the Physiotherapist**

Given our work with the physiotherapists, the most promising avenue is to develop support for home exercise in the absence of the physiotherapist. Because this work at home between sessions plays such an important role in treatment outcomes, it is likely that supporting this activity well will prove most beneficial to patients in the long run. Given that physiotherapy exercises are dynamic, providing the patient with videos of exercises being properly
performed is likely more effective than a static handout. These exercises should be tailored to the patient, perhaps even with the patient as a model (i.e. using a recording of the patient performing the motion correctly during a session with the physiotherapist), and the recordings could double as a mechanism to track progress over time. In fact, creating custom videos may actually be quicker and easier than giving a handout that requires in-depth description and instruction. Furthermore, just as the patient mimics the therapist’s demonstration of the exercise, the recording could be played back “in the mirror”, allowing the patient to perform the exercise next to himself as the model.

Guidance is the most promising feature that current commercial tools are providing [15], and lessons should be taken from these and other tools like MotionMA and LightGuide [21, 27]. Patients have a hard time following directions on a handout and may recreate exercises from a video incorrectly, but having some kind of virtual guidance and correction of improper motions would ensure that the patient is always moving the way the physical therapist expects him to, and adds a level of interactivity that does not exist for this task. Tools for correction must provide adequate, clear feedback for correction of complex motions, with fine enough detail that the patient can understand corrections, but not so fine that he is only able to focus on one point of his body at one time. Adding joint tracking information to the mirror probe, recording a proper movement with the patient, having him exercise within his recorded representation, and providing adequate feedback when he makes a mistake is a solution worth exploring. This addresses the issue of customization of exercises, provides good visual feedback, and should better train proprioceptive senses.

**View and Annotation: The Body as a Workspace**

The issue of designing for meaningful interaction between remote collaborators using flat workspaces has long been a challenge for researchers in CSCW, and tasks that require collaborators to work around a person’s physical space add a lot of complexity. Movement instruction is complex and dynamic, with physiotherapy motions requiring proper placement of multiple joints and/or limbs at once, so remote instruction of this task is a major challenge. Traditional videoconferencing tools allow for some demonstration, but the separation of space between the patient and physiotherapist makes discussion and movement guidance in the patient’s workspace difficult. This separation actually creates some added distance between the collaborators, and cuts off their ability to gesture in space around the body, which is relied on for communication in collocated therapy.

Issues of being able to gesture easily, and being able to manage a remote party’s attention are important here. In Buxton’s articulation of video media spaces as comprising three spaces [3], physiotherapy offers a domain where all three spaces: workspace, person space, and reference space are necessarily merged for communicative ease. As we saw in our first probe, this eases gestural ease, as well as facilitating shared understanding of attention.

One problem with working around the body as a workspace is that people cannot see certain parts of their bodies, and CSCW systems for this task need to account for this issue. The traditional videoconferencing setup of one camera at one display is not effective in telerehabilitation, and other configurations or hardware should be explored to allow areas of the body to be rendered visible to the patient and/or physiotherapist when necessary. Patients straining and twisting to see the screen are usually not performing exercises correctly, and systems for telerehabilitation need to place importance on allowing the patient to move naturally while still being able to effectively communicate with the physiotherapist. Multiple camera and display configurations could address this issue. Physiotherapists suggested also providing patients with a tablet so that the patient could always see the shared video feed regardless of the direction he is facing.

Another issue with the body as a workspace for physical therapy is that the task deals heavily with movement guidance, which is dynamic, and is complex even in collocated work. A related application, and one that we discussed with physiotherapists and from which we took inspiration, is the on-screen annotation that a football commentator would do during the broadcast of a game. During a game, there are a number of players on the field moving in different ways, and the commentator will use annotation to focus the viewer’s interest on one or two key players while discussing a play. Similarly, while there are many body parts and joints at work in motion, there are usually just a few points of interest. During a football game, the broadcaster will pause the screen to discuss player motions clearly, which we incorporated into the annotation probe, but also uses replay and slow motion with annotation as tools for discussion. Annotation seems to be effective for supporting body movement discussion, and recording for playback and discussion should be explored further, with future probes taking further inspiration from domains dealing with complex motion such as sports broadcasting.

**Assessment is Difficult or Impossible**

Complete assessment with telerehabilitation using only videoconferencing tools seems very difficult, and our physiotherapists’ reliance on touch suggests that given their training (which emphasizes tactile aspects of assessment), they are unlikely to be happy with remote assessment generally. Over the course of the patient’s treatment, his physical therapist is constantly evaluating and re-evaluating his progress by measuring specific outcomes and tracking this information to guide the patient’s treatment plan. This process involves the collection of information through verbal or visual means, which should be possible using high-fidelity videoconferencing technology. Assessment
also involves measurement using specialized instruments or reading through touch, which is difficult or impossible remotely, depending on the measurement.

Most of our participating physical therapists expressed a need for objective, quantitative measures during assessment. These are helpful because they work as progress tracking for the physiotherapist, but the patient also needs to see progress in order to stay motivated and confident in their treatment. Allowing the physical therapist to measure angles in some way, either manually or automatically, provides these important measures that make remote physical therapy more practical. A feature for the physiotherapist to quickly select points for angle measurement, as DartFish does, could easily be added to the annotation probe for manual angle measurement and would work like a virtual goniometer [7]. More research needs to be done to determine how effective telerehabilitation assessment methods are, and how relatively inexpensive consumer hardware like the Kinect may be utilized for this task.

While it is outside the scope of this work, combining sensor-based technologies with videoconferencing tools would better address the issue of no tactile feedback during remote assessment. For example, physical therapists could set up pressure sensors in the patient’s home for strength testing, or they could use sensors to measure skin temperature, which they would subjectively do by feeling the skin in collocated physiotherapy.

CONCLUSION

Physiotherapy is an effective treatment for common injuries, but remains difficult to access for many individuals. The work we present here represents a starting point for designing next-generation telerehabilitation tools that account for the communication practices of physiotherapists. In particular, we demonstrated that if only conventional technologies are being used, we need to augment videoconferencing tools to account for the fact the body is now a workspace, and that lessons from video media space work should be adapted here to support nonverbal communication (gesture, gaze), though the dynamic and complex nature of physical movement will need to be accounted for. While our probes are a step in this direction, they were only designed to identify and learn these lessons.

In spite of this, it seems at this point that certain aspects of the physiotherapy process may never be completely conducted in a remote setting. Manual therapy requires the physiotherapist to touch the patient, and is impossible in a remote context. As discussed, certain types of assessments requiring touch are also not possible using available technologies. Our work shows, however, that technology can be utilized to decrease the amount of collocated interaction that is necessary in physiotherapy, decreasing the physical, financial, and emotional burden of accessing services for remote patients. Videoconferencing tools can be designed to allow for better visual communication, accounting in some way for the lack of tactile communication in telerehabilitation.

Our work has certain limitations, though we believe the results are quite valuable. Our participant pool was mostly female, all working in the same city (so therefore maybe sharing in similar practices), with most having fewer than five years experience. Thus, the perspectives we received may not have been meaningfully divergent. Nevertheless, since our work is very early and exploratory, the feedback is useful in moving us forward.

Our work should serve as a starting point for thinking about designing telerehabilitation tools that account for existing communication practices. For the broader community, we see that the ideas stemming from this work should serve to inform other research that requires or implicates movement instruction (e.g. exercise, dance, etc.). Whereas the traditional CSCW notion of a "workspace" has focused on flat surfaces, the insights from this work provides a fresh perspective on how the body can constitute a workspace in of itself.

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