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technical report

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Abstract. Many common injuries can be treated effectively with physiotherapy, but accessing this treatment is difficult for those in rural locations. We seek to design video-based systems to support remote physiotherapy, so patients can access and engage with therapy and a professional from their homes. We conducted design sessions with practicing physiotherapists to iteratively design and build technology sketches to understand communication challenges and practices for remote therapy. Our analysis of these sessions reveals new challenges in designing video media space tools for telerehabilitation. Chief among these lessons: supporting body-based communication between therapist and patient is challenging because the object of conversation is the patient's body rather than an external object that can be manipulated.

Keywords. physiotherapy, remote collaboration, telerehabilitation

1 Introduction

For many injuries and movement disorders, physical therapy (physiotherapy), can increase mobility and decrease disability for patients receiving treatment [33]. In the case of an injury like rotator cuff tendinitis, a physiotherapist guides patients through (and assigns as homework) exercises such as in Figure 1 in order to rehabilitate the patient. Those living in cities, where most physiotherapists operate [6], tend to be served well by physiotherapy services. Yet, those who live in rural areas, where manual labour is an occupational norm (in Canada, over 18% of the population live in rural areas [27]), not only suffer a disproportionately large number of such injuries [18], but do not have easy access to physiotherapy professionals. As we learned from our design sessions with practicing physiotherapists, asking rurally based patients to travel into the city to access services can exacerbate many such injuries (e.g. sitting for hours during travel can worsen a back injury).

Our goal is to design technologies to enable remote physiotherapy, where a patient at home can work with a professional physiotherapist for guidance in movement exercises. In particular, we envision near-future possibilities for providing support for such sessions through commodity hardware already in people's homes, for example with laptops equipped with web cameras, or in living rooms equipped with commodity depth cameras attached to gaming systems and large displays (e.g. Xbox Kinect camera). While our explorations are predated by years worth of work in telerehabilitation (e.g. [19], [13], [20], [22], [33]), our interest here is going beyond the simple possibility of telerehabilitation; instead, we are focused on the specific conversational and coordination actions that are necessary to make telerehabilitation work. We narrow our scope to physiotherapy for several reasons, chief among these being that the basic biomechanics of motion can be modeled by a commodity depth-capture system such as the Kinect. We are therefore guided by three central questions in this work: first, what are the communication practices in traditional face-to-face physiotherapy that must be preserved; second, what challenges does video media space present to these practices, and third, how can technologies be designed to overcome these challenges?

To support our inquiry, we ran several design sessions with five practicing physiotherapists. We used these sessions to iteratively design and implement three separate video media space technology sketches, each of which focuses on distinct aspects of physiotherapy practice: the *mirror* sketch facilitates body communication by allowing the remote professional to appear as a "ghost" atop the patient's scene, allowing him/her to demonstrate exercises alongside the patient, and to point at parts of the patient's body; the *annotation* sketch allows the remote professional to freeze the patient's scene, and to annotate it with a tablet-based interface, thereby allowing the therapist to communicate about body parts that may not be visible to the patient, and finally, the *target* sketch provides patients with the ability to revisit exercises learned from prior sessions, going beyond current practices of giving patients paper diagrams of exercises.

These sketches reflect our understanding about how physiotherapists use the patient's body and surrounding environment to communicate with patients, the role of mirrors, and home exercise. This is a unique scenario, seldom explored in video media space research.

For many video media space designs, the object of conversation is a physical or digital artefact that can be placed and manipulated on a flat work surface (e.g. [30], [10], [29], [12], [37]). Considerable work has demonstrated that allowing all participants of the video media space to see this task space can aid communication and comprehension (e.g. [5]). In contrast to this, a patient undergoing physiotherapy needs to not only perceive and understand the object of discussion, but is also now him/herself the object of conversation (i.e. s/he *is* the workspace).

We make two contributions in this work. First, we provide insights into a specific domain (physiotherapy) that can be used to guide design of video media spaces for remote work in this area. Second, from this work, we explore the concept of the body as a workspace, developing this idea through both sketches and critical reflection of our experiences. 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 (e.g. dance, personal training, martial arts, etc.).

1.1 Physiotherapy Process

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. 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, manual therapy (e.g. the physiotherapist physically massages the shoulder), and discussions about home-treatment.

As a running example, we make reference to a common exercise: external rotation (Figure 1). As one physiotherapist explained, this exercise is commonly prescribed for patients with rotator cuff tendinitis, a condition that commonly results from overhead reaching such as painting or window washing. In this exercise, the patient holds a resistance band, keeps the elbows tight against their sides, and pulls the band outward, their forearms pivoting around the elbows. While performing such an exercise, there are a number of pieces to consider: keep the elbows in tight, keep the forearms parallel to the ground, pinch shoulder blades together, stand upright and do not slouch, do not rush, only go to a certain extent, etc. This is clearly a complex movement, and any one of these parts not happening correctly can mean the exercise is being performed incorrectly, thereby rendering it far less effective.

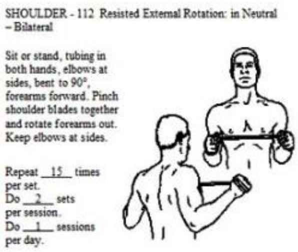

Fig. 1. An example [35] of a handout with an exercise that the physiotherapist might prescribe to the patient. This illustrates the external rotation exercise.

2 Related Work

To set the stage, we discuss prior work that has demonstrated that telerehabilitation can be a viable and effective means of restoring bodily function. We then describe recent work that has explored movement guidance through visual feedback, in some cases, also with potential physiotherapy applications. As we are interested in how this can be applied in a video media space, we explore how video media spaces have been used to enable skill instruction, and then finish by discussing the various roles bodies play in video media spaces.

2.1 Efficacy of Telerehabilitation

Early pilot studies of telerehabilitation show promising objective and subjective results [13], [20], [33], with joint replacement and stroke therapy being common conditions for study [19]. 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 [20], [33]. 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 [13]. Furthermore, there seem to be high satisfaction levels for both patients and physiotherapists in spite of the lack of face-to-face time [32].

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 [8], [22]. 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 [21]. 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 [22], important since complete assessment also involves understanding the patient's entire living environment.

2.2 Solo Physiotherapy at Home

Physio@Home. Physio@Home [31] provides physiotherapy patients with automated movement instruction while performing pre-recorded exercises. The Physio@Home system aimed to improve upon previous systems for movement instruction (ex. [2], [26], [34]), making use of advanced motion tracking to allow for instruction of complex, fine-grained movements. While using Physio@Home, the patient stands in front of a monitor, which acts as a virtual mirror, and is led (using feedback and feedforward) through complex shoulder exercises using on-screen visual guides. While appropriate for solo activity at home, we extend this work by exploring how the ideas can be used for live communication between remote physiotherapist and patient. This work raises the issue of multiple views for movement instruction, and articulates a vocabulary for unpacking the complexity of physiotherapy movements.

Movement Guidance. Other 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 hand, and guides the user through specific, fine-grained gestures using feedback and feedforward cues [26]. While this approach seems effective, it may be of limited use in a physiotherapy context, as many body parts are inappropriate for projection (and/or the projections may not even be visible). MotionMA provides visual feedback based on models of body and movement to guide a user in exercises [34], though this specific approach provides very coarse grained feedback, instructing the user to translate one or two bones of interest vertically or horizontally. While these tools focus on communicating through a visual channel, recent work has also made use of haptics to guide people through exercises [1], simulating the touch this person would receive from a collocated trainer or teacher.

2.3 Skill Instruction in Video Media Spaces

Several video media space systems have explored supporting non-verbal activity for group work over remote surfaces, including gestures, and eye contact [10], [30]. 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 [30]. 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 [10]. 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 [36].

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.

2.4 Role of the Body in Video Media Spaces

In his conceptual reframing of video media space research, Buxton [5] describes two fundamental conceptual "spaces" that bodies occupy in video media spaces: *people space*, and *reference space*. People space is where one reads expression, trust, gaze, where the voice comes from, and where one looks when speaking to another—usually supported via an audio-video link that focuses on the participants' faces. Reference space is where people use their bodies to reference the work, for instance by pointing and gesturing—usually supported via a video link that focuses on participants' arms as they work over a flat, shared workspace (e.g. [30]). Thus, we see that the body, in traditional video media spaces, performs at least two functions: first, as a means through which people can communicate and express intention and ideas verbally (i.e. through spoken language), as well as non-verbally through facial expression; second, the body acts a means through which shared reference is established, by allowing people gesture using their hands—for example to point at things.

Beyond this, bodies support consequential communication—the information unintentionally generated as a consequence of an individual's activities in the workspace, and how it is perceived and interpreted by an observer [24]. A person's activity in the workspace naturally generates rich and timely information that is often relevant to collaboration. For instance, the way a worker is positioned in the workspace and the kinds of tools or artefacts he is holding or using tells others about that individual's current and immediate future work activities. Thus, in addition to the first two roles, the body also plays a third role in video media spaces to implicitly communicate one's intentions through one's bodily actions.

Of note is that in traditional video media space work, participants are typically working atop some kind of shared work surface such as a table (e.g. [30], [29], [37]). As such, the body plays an articulatory role in supporting interaction in these video media spaces—that is, it is used to refer to artefacts that exist in a workspace apart from one's body. In the case of physiotherapy application domain, a person's body plays the role of a "workspace" in that conversation and communication occur *about the body itself.*

Thus, one of the principal challenges in designing video media spaces for physiotherapy is that the frame of reference is reflexive. That is, the workspace itself is one's body, rather than an external entity. For instance, if one were speaking about movement pain in a joint, one would point to the joint, move to the angle where the pain begins, and point at the source of the pain. Yet, this kind of approach only works well for parts of one's body that one can see; it does not work well for things that one cannot easily see (e.g. one's back). These are new kinds of problems that we have not yet encountered in traditional video media space work.

Summary. Prior literature has shown that telerehabilitation can help providing people with effective treatment for ailments, even when they are not co-present with a therapist (e.g. [33], [20]). Yet, none of this work explores the specific communication challenges that arise as a consequence of physiotherapy. Instead, considerable work has investigated how we can remove the therapist altogether, focusing primarily on the movements and training and teaching exercise (e.g. [31], [2], [34]). To foreshadow our explorations, we have discussed how prior work in video media spaces has conceptualized the role of the body. We have seen that the body needs to play a reflexive role in physiotherapy, because the discussion and communication in the media space is about one participant's actual body.

3 Design Sessions with Physiotherapists

Physiotherapists teach patients strengthening and flexibility exercises, correcting improper motions through movement guidance, and providing hands-on manipulation for assessment and therapy. The patient also performs exercises between sessions to build strength and/or flexibility. While relying on online technologies to support total assessment seems unlikely, there is considerable potential to use technology to enable the teaching and correcting of exercise movements remotely.

To this end, we recruited five actively practicing physiotherapists who participated separately in design sessions that consisted of interviews about their practice, observation of their use of technology sketches (as we designed and implemented them) in mock physiotherapy sessions, and discussions about their experiences with the sketches to support further iteration. Our primary interest was in understanding and designing to support their communication practices when working with patients in a remote physiotherapy scenario. As detailed in Table 1, some physiotherapists made repeat visits as we continued to develop sketches to further our inquiry.

Physio #	Gender	Experience (years)	Specialty	Sessions	Sketches
P1	M	3	Orthopedic	1	M
P2	F	1	Orthopedic	2	M, T
P3	F	5	Geriatric	2	M, T, A
P4	F	<1	Inpatient	1	M
P5	F	15	Orthopedic	1	M, T, A

Table 1. Physiotherapist participants. (M = Mirror, T = Targeting, A = Annotation)

The earliest meetings with physiotherapists were exploratory, and served to provide us with a basic understanding of how physiotherapists work in practice. This included: interviews about the types of treatment provided, what a typical session looks like, how health issues are assessed, and how treatment is delivered in person. After getting an understanding of the process, we engaged in collocated mock treatments with the therapists to experience physiotherapy from the patient's point of view. In these mock treatment sessions, one of the authors would act as the patient, so as to experience the session first-hand. We used the mirror sketch as a starting point for our remote physiotherapy design. Results from the mirror sketch sessions led us to create the targeting sketch, and finally the annotation sketch. All sessions were video-recorded for transcription and further analysis.

While actual physiotherapy patients did not participate in these discussions, we relied on our physiotherapists to use their experience to predict how the patient might react to the various sketches. We also drew on our own experience communicating and engaging in physiotherapy as actual patients, giving increased value to the mock therapy session method.

4 Technology Sketches

Sketching is an important part of the design process, and is a cheap and effective way to approach a new problem space [4]; where prototypes are meant to be didactic and refine an idea, sketches are evocative and allow for exploration. Rather than creating prototypes, we chose to create simple technology sketches through the course of our discussions with physiotherapists, which allowed us to explore the remote physiotherapy space without committing to any one solution.

We iteratively designed and built three different sketches: a *mirror sketch*, where the physiotherapist and patient are represented as if they were in a mirror together, an *annotation sketch* that allows physical therapists to draw on and around the body of the patient, and a *targeting sketch* that allows a physiotherapist to define a path of targets for the patient to move through. These sketches were built using C#/WPF, large projection screens, and the Microsoft Kinect camera. To mimic remote sessions with the physiotherapists, we created a dual setup to enable paired videoconferencing environment in our lab, and used these in our design sessions.

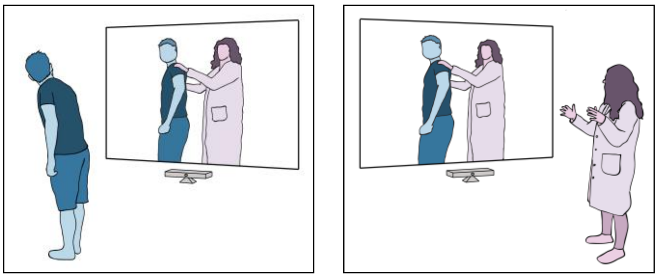

Fig. 2. View of the physiotherapist's (right) and patient's separate physical workspaces, with shared workspace displayed on each participant's own display.

4.1 Sketch 1: Mirror for Shared Discussion

Figure 2 illustrates the first sketch, a videoconferencing environment where each participant is made to feel like they are sharing a mirror with remote participants [15], [14]. The depth cameras respect the relative spatial relationships between participants as illustrated in Figures 2 and 3 [14]. We based this first sketch on our own experiences in physiotherapy, 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. The physiotherapist can also gesture at parts of the patient's body if it is not moving or positioned correctly. Figure 3 illustrates client perspective.

For contrast, we also built a standard videoconferencing 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 sketch.

Fig. 3. Screen capture of mirror sketch. Inset image shows view of the patient's space (enhanced for clarity).

4.2 Sketch 2: Annotation of the "Bodyspace"

Our second sketch focused on providing therapists with a means to annotate the patient's body and the area around it. A therapist can use this by freezing the video scene (with the patient's body in it), and the therapist can annotate the image using a variety of colours and brushes to illustrate different aspects of movement, or orderings (e.g. blue movement comes first, then red, etc.). As Figure 4 illustrates, the tablet provides the therapist (and/or patient) with a view of the video scene. The live video scene can also be annotated so that, for example, the patient can know the extents of a movement (i.e. the arm should not move further than point X, or lower than point Y).

Fig. 4. Illustration of the physiotherapist using annotations to guide the patient's hand. Inset image shows the physiotherapist's view of the tablet.

4.3 Sketch 3: Target Paths for Movement at Home

To support at-home exercises, we designed the third sketch to allow a physiotherapist to define a movement path through space (through a set of targets) that a patient could later "retrace" at home (Figure 5). Here, we drew on themes from prior work emphasizing notion of feedforward and feedback in guiding movement through space [31], [26]. The 2D targets are displayed on-screen "in" the patient's environment, 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).

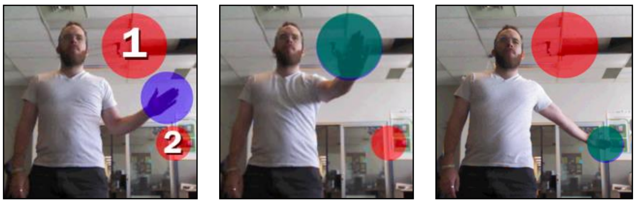

Fig. 5. The patient interacts with targets that have been placed by the physiotherapist. Target 1 is closer to the screen/camera than target 2.

5 Findings and Discussion

We summarise the findings from our design sessions with the physiotherapists in three categories: communication and movement guidance, assessment and progress tracking, and exercising at home. In each, we discuss current practices and how the physiotherapists expected these practices to be augmented with the sketches. Finally, we provide our own thoughts about how to deal with these issues, while considering the body as a workspace. Unless otherwise noted, all information in the findings resulted from our design sessions with physiotherapists.

5.1 Communication and Movement Guidance

Findings. Physiotherapists teach patients new exercises and movements first through demonstration, and second through gesture; if these fail, they fall back to physically guiding the patient through touch. The physiotherapist usually demonstrates the proper exercise to the patient so that he can see the entire form. Therapists will also use gesture, pointing at various body parts to indicate what should stay still, what should move, and how far. This often happens 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. In colocated treatment, the physiotherapist can mark up the mirror to better train proprioceptive senses, or his awareness of his body's position in space [28]:

[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 a patient with a view of himself, nor for the physiotherapist to meaningfully help guide motion. The physiotherapists encountered issues in conventional videoconferencing with the patient not understanding verbal instructions, and the inability to point made clarification challenging. We also observed issues with the way the conventional videoconferencing setup presented two different views for the different users; the local view presented in the corner of the display sometimes occluded the image of the remote person, causing confusion. In contrast to the conventional setup, the mirror and annotation sketches worked extremely well for the therapists. Placing the patient next to the physical therapist in a mirror image (as in the mirror sketch), allows the therapist to easily model the ideal version of an exercise. The patient can then mimic the movement simultaneously, which is a way that people learn movements [23]. This demonstration happened in two different ways: physiotherapists P2, P3, and P5 instinctively stood beside the patient in the space, but P1 and P4 tended to stand in front of and/or behind the patient. P1 thought it would be compelling to overlay the images, as the therapist's body could therefore act as an explicit visual guide:

Can you make it like a translucent image? Then you could still see me, but could also see yourself. Then you could try to mimic the movement. [P1]

The mirror sketch also allowed the therapists to make and use the same gestures that they commonly use in collocated therapy to guide the patient (Figure 3). Interestingly, as much as exercises are about movement, they are also about keeping particular bodily parts still. To this end, the annotation sketch could be used to provide a reminder to keep a body part still. For instance, the external rotation involves proper positioning of the elbow, shoulder, and back, so being able to quickly reference and mark joints is necessary. As an example of how this might play out in remote physiotherapy, this vignette illustrates how a therapist would use the sketch to guide a patient through a similar exercise:

(Drawing a dot on the patient's shoulder.) So right there, I want you to try and keep that point still while you lift your arm up and come back down. (Patient's shoulder moves away from dot.) And you can see how it comes forward and comes up a little, so try and keep it more still in space as you lift. [P5]

Similarly, the targeting sketch could be appropriated to help indicate to a patient that his arm has moved too far one way or another (since the target changes colour when the body part passes over the area).

Finally, there were multiple instances of the patient not being able to see certain parts of the body. For example, P5 attempted to get her patient to perform a back exercise and asked him to turn his back to the camera. Upon learning that the patient could no longer see himself, she had him turn to the side as a next-best option. Incidents such as this one prompted discussions about: pausing the video so the patient can see their back, being able to record and replay video, or having the patient hold a tablet to be able to turn their back to the camera and still see a view of the back.

Discussion. As illustrated in Figure 1, even physiotherapy exercises that seem simple are complex given the number of ways that they can go awry. While a basic audio-video link is clearly better than an audio-link alone, the mirror sketch added a new dimension to the interactions between therapist and patient as described above. Nevertheless, a major limitation of this communication is the inability of the physiotherapist to be able to guide the patient through touch. While there are some emerging solutions to this problem that, for example, explore haptics [1], these typically require additional equipment and instrumentation. In the absence of touch, employing new configurations of the video space (i.e. as a mirror) may be the most straightforward way of addressing this communication gap.

As discussed in other work [34], [31], it is important to provide both feedback and feedforward information to the patients in a dynamic, timely way. Visual guides such as those provided by Physio@Home present more visual information to the patient than is possible in collocated therapy [31], and this begins to make up for a lack of tactile communication between patient and physiotherapist. An interesting question may be to explore where the feedback is presented. While several systems employ a mirror-style approach ([31], [34]), it may be interesting to explore providing this feedback through on-body projections as in LightGuide [26], or projecting on the floor or ceiling.

Our design sessions revealed two additional challenges arising from the need to discuss parts of the patient's body, with the body acting as the workspace. First, the patient's body is frequently in motion. Annotations on the live video rapidly became out of sync with the patient's body and irrelevant. Second, the patient might not be able to see certain parts of his body that might need to be annotated (e.g. his back), or that might need to be discussed. We resolved this in our sketches through the addition of a "pause" feature, which addresses the latter problem, but less so the former (i.e. dealing with motion). Other possibilities could be to include a "playback the last 10 seconds" feature that could be annotated, multiple cameras, or bodily-tracked annotations (that follow the body even as it moves in the camera view).

One of the biggest problems with movement guidance is that with current generation of commodity tracking technologies (e.g. Kinect), they are still unable to support fine-grained movement tracking well enough for many physiotherapy exercises [31]. Providing the physiotherapist and patient with an effective live communication tool, one that addresses the issues presented when treating the patient's body as the workspace, should still make performing remote exercises safe and practical. This requires more time from the physiotherapist, since they must actively work with the patient, but cuts down the amount of travel required by both physiotherapist and patient. More work should be done to refine the technology sketches, and test the accuracy of patient movements when guided in various ways.

5.2 Assessment and Progress Tracking

Findings. A therapist tracks a patient's progress through recovery using both experience (i.e. "reading" a patient through her hands), as well as with formal tools such as a goniometer (akin to a protractor). Common measures include strength, flexibility, as well as pain. Physiotherapists are trained to use touch to gain information and assess the patient, which presents a major issue when touch is not possible, as in remote physiotherapy. Visual inspection is also used by the physiotherapist for assessment. For example, the patient might demonstrate an exercise for the physiotherapist to assess visually, or she might also check for things like skin tone or hair growth. Patients will also communicate a lot of information through non-verbal cues, such as facial expressions and recoil; so-called "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]

For precise range of motion assessment, our participants felt that being able to actively display joint angle information for patients would be valuable, particularly if it was an automatic feature (skeleton tracking can be used to approximate these values). When asked about the potential to do assessments, P3 agreed that she could use the mirror sketch to assess her back patients, though that she would "like to put sensors on them to have an objective measure" of range of motion automatically. For example, in the external rotation exercise, the physiotherapist may want to know how the patient is progressing by measuring the angle between the forearm and chest while pulling the resistance band. Beyond precise quantitative measures of range of motion, it became clear that "approximate" measures of progress were sufficient in many cases (and would be particularly motivating for patients):

The numbers are really good for motivation, and they need that to stick with their therapy. They need to see that motivation. If they're thinking, "Oh my gosh, my numbers aren't getting any higher", they're going to be discouraged. [P2]

Discussion. While assessment of certain variables traditionally assessed through hands-on interaction may never be practical or possible remotely, certain visual assessments may be possible remotely using the features afforded by the technology sketches. This should serve to decrease the number of face-to-face appointments necessary, in turn easing the burden on rural patients.

One of the major problems encountered with visual inspection and assessment in remote physiotherapy is the fact that the physiotherapist no longer has the space to work around the patient, and is limited to a single-angle view when using videoconferencing. In collocated therapy, the physiotherapist can get close to the patient for a "zoomed in" view, and can kind of walk and "pan" around the patient for different vantage points, and none of this is possible with a single-camera videoconferencing system. As in Physio@Home [31], multiple camera views can begin to address this issue, and allowing a therapist to remote control a video-capture drone in the patient's space may be an interesting alternative [17].

To support some range of motion assessment, the annotation sketch could be used to mark the extents of a movement, and these annotations could be compared across time to show progress. As a visual charting tool, this would become immediately useful for the therapist, and a useful motivational tool for the patient. Similarly, playback of past attempts over time (compared to one's current progress) could be used.

5.3 Exercising at Home: Video for Later

Findings. Therapists provide patients with exercises to perform between treatment sessions. To this end, physiotherapists provide patients handouts with images and descriptions of how to perform the exercises (such as in Figure 1). The main challenge is the lack of guidance for the patient when they arrive home—performing these exercises improperly will certainly result in less than ideal treatment outcomes. Furthermore, patient-specific modifications are rarely captured on such handouts, requiring the patient to remember the modification.

All therapists felt that video recordings of exercises would be a useful resource for patients—particularly if they could be accessed in the mirror sketch, such that patients would thus be able to use the recording as a model. This, it was thought, might prompt better muscle memory:

They have done it before. The pictures we give them are not always exact; it's a picture of someone else doing it. If we had a picture of them doing it perfectly, the way we want them to do it, and they said, "Ok, that's where my hand was. That's me doing it." I think it would be easier for them to get back into that position, than seeing someone else do it. [P2]

Since the mirror sketch uses depth, the patient could even step inside his former representation to try to match the movement [3].

Our physiotherapists agreed that an important feature to include for exercising at home between sessions would be some kind of guidance akin to the basic ideas expressed by the targeting sketch:

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]

Our targeting sketch resonated most closely with stroke therapy, since, as we learned from P5, 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 sketch.

Discussion. Because the exercises at home between sessions play 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 frequently dynamic (i.e. non-isometric), providing the patient with videos of exercises being properly performed is more effective than a static handout [11]. These exercises should be tailored to the patient, perhaps even with the patient as a model (e.g. by 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. These videos could be as simple as recordings made during meetings with the physiotherapists. 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.

In some ways, Physio@Home embodies many of these ideas, providing patients with feedback and feedthrough to reproduce the movements. Yet, Physio@Home provides only limited recording capabilities. It seems clear that recording previous "successful attempts" at the exercises (e.g. from sessions with therapists) may also be useful and effective guides for patients at home. Future systems could even make use of multiple cameras to capture a multi-view capture, giving patients multiple perspectives on these captured sessions.

6 The Body as a Workspace

Movement instruction is a complex and dynamic task even when colocated, with motions requiring proper placement of multiple joints and/or limbs at once. Current videoconferencing tools (e.g. Skype) 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 creates some added distance between patient and therapist, and cuts off their ability to gesture at or manipulate the patient's body, which is relied on for communication in collocated therapy.

Our domain-specific exploration of physiotherapy shows us that here, the body becomes the subject of conversation (i.e. the workspace itself). Buxton's three-space articulation of video media spaces is useful here [5], where person-space comprises a space for relationship and trust development, task space is where work is accomplished, and reference space is where people can refer, point, and relate with one another in the task space. Physiotherapy offers a domain where all three spaces are necessarily merged (i.e. patient's body is all of person-, task-, and reference- space). Retaining this unified presentation, as we saw in the mirror sketch, eases gestural interaction, as well as facilitating shared understanding of attention.

Yet, in general, having a body as a workspace in a video media space presents a number of challenges for both the "teacher" and "student" that need to be reconsidered due the fact that the subject of work and conversation is a participant in the media space rather than a separate, static entity that can be manipulated independently.

Challenge: Visibility. People cannot see certain parts of their bodies in real life—we learn and receive feedback about muscles and movements on our back through tactile and kinesthetic feedback, or through the use of mirrors. The traditional videoconferencing setup of one camera at one display is therefore not ideal in telerehabilitation, and other configurations or hardware should be explored to allow areas of the body to be rendered visible. Patients straining and twisting to see the screen are usually not performing exercises correctly. Additionally, physiotherapists lose the ability to move freely around the space of the patient during remote therapy. Multiple camera and display configurations could address this issue (as in [31]). 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.

Challenge: Annotations. Annotations are semi-permanent mark-ups on the workspace that allow people to read/refer to ideas and information. Because the workspace here is a person's body and the space around it, these annotations need to be "connected" to those body parts and/or the space around it. For instance, our annotation sketch presented problems as soon as a person moved (even a limb) in the video scene—arrows would no longer point to the right body parts, or may even be pointing in the wrong direction. Furthermore, those annotations were in 2D space, many movements may be in the entire 3D space.

Challenge: The "workspace" is non-static. Particularly in relation to movement guidance, the "workspace" is a moving, living, and breathing entity. Because the patient can freely move about, and movements have a temporal element, gestures and annotations about these movements also need to have a temporal element. This is realized in YouMove [2] and ChoNo [25], [7], where annotations are layered as "tracks" that are only visible for specific durations. Yet, while this solution works for an asynchronous situation, how can we design these for real-time interactions when a remote physiotherapist is working with a patient?

Challenge: Capture Resolution. The granularity of current depth-camera based sensing systems (i.e. Kinect) may limit the value of current systems, depending on the task. For instance, several research and commercial systems have been developed to help teach movements such as exercise (e.g. [16], [9], [34]) and dance [7]; in these cases, the guidance is strictly for position and movement of gross body parts (e.g. upper arm, lower arm, torso). Limitations of the sensing system mean that these systems cannot detect slight twisting or torquing motions, and subtle changes in hand position or other joints, which are important factors in certain movements.

Challenge: Attention. Specifically in the context of movement guidance, many body parts and joints may be in motion at the same time—how do we draw one's attention to the right point of interest? In mock sessions with the physiotherapists, we noticed sometimes that deictic references to body parts (i.e. "Move that upward"), if misinterpreted (e.g. moving the hand upward rather than the elbow), would lead to situations where the entire exercise would need to be reset. Thus, while annotation seems to be effective for supporting body movement discussion, and recording for playback (or slow-motion replay) and discussion should be explored further.

Challenge: Movement Complexity. As illustrated in the external rotation exercise (Figure 1), even seemingly simple motions like moving the patient's forearms across their body are actually quite complex, and many parts of the body are involved. One of the main challenges is related to proprioception: there is often a disconnect between how we think we are moving and how we are actually moving. We may also focus in too closely on the motion of one part of the body and neglect another. An additional problem is that the body is made up of a number of joints, each with multiple degrees of freedom; these must all coordinate correctly to execute a proper motion. If learning these movements were simple, there would be little need for professions such as dance instructor. On-screen annotation can support this type of instruction, and Physio@Home showed that breaking the movement down into smaller "chapters" made it easier for patients to learn the complex motion.

7 Conclusions & Future Work

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 telerehabilitation tools for physiotherapy. Video conferencing tools need to be augmented 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 non-verbal communication (gesture, gaze), though the dynamic and complex nature of physical movement will need to be accounted for.

Our work has certain limitations: 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 of experience. Thus, the perspectives we received may not have been meaningfully divergent. Also, while the insight provided by physiotherapists regarding patient communication was incredibly valuable, the lack of actual patient participation is a limitation, and patients should be involved in future studies. Nevertheless, the findings have been helpful in informing our work moving forward, particularly as it relates to designing video media space systems where a participant's body is the workspace, and we see this work as informing next steps for similar telerehabilitation tools.

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