Towards At-Home Physiotherapy: Next Generation Teleconferencing and Surface Based Interventions

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Introduction

Hundreds of thousands of Canadians regularly sustain soft tissue injuries best suited for physiotherapy intervention, but many of these Canadians live in rural areas—away from the urban centres where most physiotherapists practice. This chapter describes two threads of work to address this problem: first, explorations of teleconferencing technologies to enable physiotherapy "visits" with remote practitioners, and second, explorations of at-home technologies that can support daily physiotherapy exercise. We discuss promising avenues of inquiry, and outline paths for ongoing future work.

For many injuries and movement disorders, physical therapy (physiotherapy), can increase mobility and decrease disability for patients receiving treatment (Tousignant et al., 2011). 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 (Canadian Institute for Health Information, 2011), 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 (Statistics Canada, 2012)), not only suffer a disproportionately large number of such injuries (Peek-Asa et al., 2004), 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 allow patients to perform physiotherapy exercises from their homes. In particular, we envision near-future possibilities 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 (e.g. the Xbox Kinect camera can model basic biomechanics of bodily movement). Using these technologies, we envision patients speaking directly to professional physiotherapists to receive movement guidance, or smart video-based systems that can train, instruct, and correct patients when performing exercises.

We are 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?

We explore these questions in this chapter through two explorations. In the first, we worked with physiotherapists to understand how to design tools to enable patients to work with physiotherapists live—for diagnosis and exercise training. In the second, we explored the 'at-home' case of doing exercises between physiotherapist visits.

Our explorations in this space have resulted in four sketch/prototype systems that point to useful directions for designers looking to support physiotherapy in future systems. As a group, the 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.

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.).

Physiotherapy Process

Physiotherapists work with 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 refer to a common exercise: external rotation (Figure 1). 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 a complex movement where performing any one of these parts incorrectly renders it far less effective.

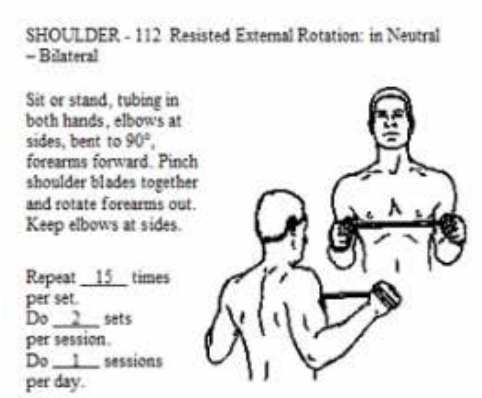

Figure 1. An example of a handout with an exercise that the physiotherapist might prescribe to the patient. This illustrates the external rotation exercise.

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 explored movement guidance through visual feedback, and finish by discussing the various roles bodies play in video media spaces.

Efficacy of Telerehabilitation

Early pilot studies of telerehabilitation show promising objective and subjective results (Lai et al., 2004; Russell et al., 2011; Tousignant et al., 2011) with joint replacement and stroke therapy being common conditions for study (Rogante et al., 2010). 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 (Russell et al., 2011; Tousignant et al., 2011). 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 (Lai et al., 2004). Furthermore, there seem to be high satisfaction levels for both patients and physiotherapists in spite of the lack of face-to-face time

(Tousignant et al., 2011). The literature suggests that assessments involving coarse-grained detail, such as gross movement or patient environment, are well suited for remote assessment (Cabana et al., 2010; Sanford et al., 2013). However, in cases where physiotherapists must use touch (e.g. feeling to check whether a joint is moving properly) remote assessment is not possible.

Solo Physiotherapy at Home

Home-based Physiotherapy. Related to telerehabilitation works are home-based physiotherapy systems for self use. These allow the patient to exercise and receive feedback whenever they exercise, regardless of whether their physiotherapist is available. Some prior systems used wearable sensors to track patient limbs (Ananthanarayan et al., 2013; Ayoade & Baillie, 2014), but commodity depth sensors like the Microsoft Kinect are showing promise for at-home use (Doyle et al., 2010; Huang, 2011; Yeh et al., 2012). These systems use visuals on computer displays to provide feedback. The visuals range from pre-recorded video of a physiotherapist (Doyle, 2010; Huang, 2011) to stylized 3D representations of limbs (Yeh et al., 2012; Ayoade & Baillie, 2014). Work by Ananthanarayan et al. (2013) is unique in that the wearable sensor visually depicts the knee's bend angle.

Patients using these systems lack the immediate one-to-one communications of a physiotherapist either in-person or by telepresence. While this appears detrimental to the patient: early studies by Ayoade & Baillie (2014) on their prototype demonstrated that patients using such a system at home with basic 3D visuals to supplement routine physiotherapist visits improved more over patients using traditional methods.

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 (Sodhi et al., 2012). 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 (Velloso et al., 2013), 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 (Alizadeh et al., 2014) by simulating the touch this person would receive from a collocated trainer or teacher.

Video Media Spaces for Physiotherapy

In his conceptual reframing of video media space research, Buxton 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. Tang et al, 1991). Thus in traditional video media spaces, the 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. Yet, 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 provide people with effective treatment for ailments, even when they are not co-present with a therapist (e.g. Tousignant et al., 2011; Russell et al., 2011). 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. Anderson et al., 2013; Velloso et al., 2013). In our work, we address how 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.

Exploration 1: 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. Yet, what kinds of support do patients and physiotherapists need if we are to design technology to enable this process remotely?

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.

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 acted as the patient to experience the session first-hand.

Technology Sketches for Live Physiotherapy

Sketching is an important part of the design process, and is a cheap and effective way to approach a new problem space (Buxton, 2010); 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 in our lab, and used these in our design sessions.

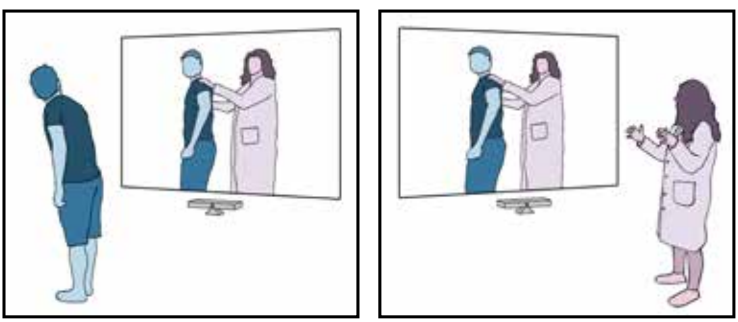

Figure 2. View of the physiotherapist's (right) and patient's separate physical workspaces, with shared workspace displayed on each participant's own display.

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 (Morikawa & Maesako, 1998; Ledo, et al., 2013). The depth cameras respect the relative spatial relationships between participants as illustrated in Figures 2 and 3 (Ledo, et al., 2013). 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.

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

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).

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

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 feed-forward and feedback in guiding movement through space (Bau & Mackay, 2008; Freeman et al., 2009; Sodhi et al., 2012). 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).

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

Findings and Discussion

We summarise the findings from our design sessions with the physiotherapists in two categories here: communication and movement guidance, and assessment and progress tracking. 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.

Communication and Movement Guidance. 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 collocated treatment, the physiotherapist can mark up the mirror to better train proprioceptive senses, or his awareness of his body's position in space (Stillman, 2002).

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 different views for each person: 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 (Schmit, et al., 2005). Some of our physiotherapists instinctively stood beside the patient in the space. One thought it would be compelling to overlay the images, as the therapist's body could therefore act as an explicit visual guide so the patient could mimic the movement.

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. For example:

> *(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, one therapist 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 prompted discussion 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 (Alizadeh, et al., 2014), 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.

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).

Assessment and Progress Tracking. 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", which might indicate pain or discomfort. The face, therefore, must be visible.

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.

> *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. 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.

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.

The Body as a Workspace. Movement instruction is a complex and dynamic task even when co-located, 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 exploration of physiotherapy shows us that when the body becomes the subject of conversation, Buxton's three-space articulation of video media spaces (Buxton, 2009), is only useful conceptually, as all three spaces are all merged into one (i.e. the 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 with 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 Physio@Home). 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 (Anderson, et al., 2013) and ChoNo (Singh et al., 2011; Carroll, 2012), 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: 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.

Exploration 2: Physio@Home for Exercising Between Sessions

We previously described sketches to enhance video conferencing interaction between patient and physiotherapist, but these sketches still require the physiotherapist to be present and working with the patient, albeit through video conferencing instead of in-person. The patient must still exercise at home on their own between routine physiotherapy sessions, but will no longer have the physiotherapist to guide and correct their exercise movements. The patient is now liable to forget their exercises, or to perform them incorrectly and risk slower recovery or re-injury.

To investigate this problem, we developed a prototype system called Physio@Home (Tang et al., 2015) to be used in patients' homes, where the patient will use the system while performing their exercises. The physiotherapist models exercises for the patient and gives them the recording files, and Physio@Home uses these files to guide and correct patient movements. The purpose of Physio@Home is not to replace the physiotherapist. Instead, it and similar systems supplement either regular in-person visits or telepresence sessions as in the previously described sketches to ensure patients are correctly performing their exercises while away from their physiotherapist. The physiotherapist is still required to diagnose their condition and provide exercises.

Characteristics of Movement

To guide exercise movements without a physiotherapist, we needed to understand how physiotherapists describe movement and motion of the body and limbs. We analyzed commonly prescribed shoulder exercises and the ways physiotherapists taught them to develop a set of important characteristics that physiotherapists use to communicate. These characteristics are illustrated in Figure 6.

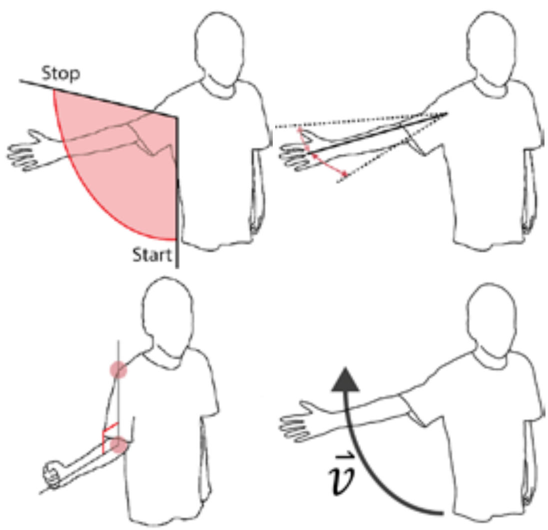

Figure 6. Characteristics of movement.
(Top, Left to Right) Plane/range of movement, extent of movement,
(Bottom, Left to Right) maintaining position/angle, rate of movement.

Plane/range of movement. This refers to the plane that the body part will move along during the exercise. The range refers to the "start point" and "end point" of this movement. For instance, during non-angled shoulder abduction, the patient's arm moves up along the frontal plane, starting from a resting position to where it is exactly aligned with the shoulder.

Extent of movement. This limits how a body part's motion can and should deviate from the plane of movement. For example, during angled shoulder abduction, the arm must maintain its angle relative to the body's sagittal plane.

Maintaining position/angle. For many exercises, certain joints need to be kept in a fixed position or at a fixed angle. In the case of abduction/adduction, the arm must be kept straightened, and the shoulder kept level with the ground. Other exercises are stricter—for example, with an external rotation exercise, the elbow needs to stay next to the body, and be bent at 90°.

Rate of movement. This refers to how fast a body part should move. For some exercises, performing them slowly ensures the right muscles are being used. This characteristic applies to a variation of the shoulder adduction where the arm must travel slower as it returns to the patient's side. In many cases, an exercise does not have a set rate of movement and patients are free to proceed at their own pace.

Wedge Visualization

We iteratively designed a visualization called the Wedge (Figure 7) using these characteristics of movement for use in Physio@Home. The Wedge consists of an arrow with a long stem to show movement path and an arc to show the plane of movement. The arc is divided into a completed section in green and the remainder of the movement in grey to show progress. This conveys both feedback and feedforward, and offers motivation for the user. When the patient is moving incorrectly from the recorded exercise, a red stick-figure arm appears to show the required position and posture of their arm.

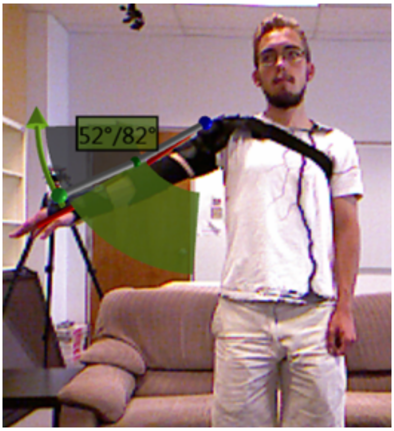

Figure 7. Wedge visualization in Physio@Home

Multiple Cameras

In addition to the frontally facing camera view, Physio@Home also provides a secondary top-down view of the participant (Figure 8). We found during early pilots that the single frontal view was insufficient for showing movements in depth, often resulting in participants not knowing how far back to move or what angle to maintain.

Figure 8. What the participant sees on-screen when using Physio@Home. (Left) View from ceiling-mounted camera.
(Right) Mirror view from forward-facing camera.

We resolved this by mounting a camera in the ceiling. This allowed the participants to see themselves from above, and thereby see their depth alignment much easier. We can also draw the Wedge from this angle with an additional visualization to clearly denote their depth alignment. The rest of the Wedge's features are also visible from this perspective. We implemented the secondary view as just a top-down perspective for now. We imagine it also being used for details the frontal mirror view alone cannot show—such as close-ups of joints, exercises done behind the patient's back, etc.

Findings and Discussion

We summarize our findings on Physio@Home and discuss the implications of the system's design features.

Study. To evaluate Physio@Home, we performed a laboratory study on 16 participants recruited from the local university. We evaluated how closely participants could follow pre-recorded exercises using the Wedge compared to simply watching and mimicking an exercise video, as is currently available for physiotherapy patients. We also evaluated the use of single and multiple camera views to see if they could benefit participant performance. Our early results showed participants being able to follow exercises the closest using the Wedge with multiple views. Overall, the Wedge outperformed the video conditions and allowed participants to follow the exercises closer.

Discussion. Physio@Home was designed to be used independently from a physiotherapist. We can also imagine it supplemented by live patient-therapist video conferencing in future work. Physio@Home's use of multiple cameras may also benefit physiotherapists. 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.

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 end. Given that physiotherapy exercises are frequently dynamic (i.e. non-isometric), providing the patient with exercise recordings being properly performed is more effective than a static handout (Kingston, et al., 2013). These could be as simple as recordings made during meetings with the physiotherapists. Currently, Physio@Home only records the physiotherapist performing the exercises for the patient to follow, but we could use the patient as a model (e.g. by using a recording of the patient performing the motion correctly during a session with the physiotherapist). These recordings could double as a mechanism to track progress over time.

Conclusions and 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.

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.