Exploring Physiotherapy with OneSpace

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ABSTRACT

With reference to OneSpace, a videoconferencing system that virtually combines the spaces of remote participants into a single depth-corrected image, we explore how the physical therapy process might be improved by making use of technology in various ways. There are two significant elements to this exploration. The first is investigative and involved design sessions with physiotherapy professionals, which allowed us to gain insight into the physical therapy process and get expert feedback about how various tools, including OneSpace, might support physical therapy. The second aspect of this work involved making actual improvements to the design of OneSpace, based on the information gained in our discussions with therapists. We apply concepts about the nature of communication in collocated therapy to the design of supportive technology, and describe the design of a prototype of a potential feature for OneSpace that would allow a therapist to guide a patient in exercises using on-screen interactive targets. The results of this work should serve to highlight current practical issues in physical therapy, especially as they relate to remote therapy, and offer suggestions for the design of future tools.

1. INTRODUCTION

In a patient's rehabilitation journey, physical therapy, commonly referred to as physiotherapy, can be an important piece of the recovery puzzle. The problem is that physiotherapy services may not be easily accessible for those who would benefit from the treatment, and even if treatment is accessible, patients often have issues performing exercises as recommended between treatment sessions. Telerehabilitation, which is "the provision of rehabilitation services at a distance using telecommunications technology as the delivery medium", attempts to address some of these access issues [10], while commercial games and novel systems have attempted to motivate and encourage proper execution of exercises in therapy patients [1, 5]. Tools to augment traditional collocated physical therapy are few, and it may be valuable to explore how technology might further enhance the experience for both therapists and patients to maximize therapeutic benefit.

Patients that must receive rehabilitation services from a therapist may be remote from the practitioner, or may be physically limited in their ability to meet in person [10]. Even if the patient were not limited in these ways, the use of remote therapy would result in time and money saved by the patient, insurance companies, and the health care system, with added potential benefits in being able to treat a person while they are in their own living space. These are all attractive reasons to pursue telerehabilitation for physical therapy treatment.

Telerehabilitation has used various technologies, which may be broadly classified in three categories: 1) image-based, 2) sensor-based, and 3) virtual environments and virtual reality telerehabilitation [10]. Image-based telerehabilitation primarily utilizes videoconferencing tools, sensor-based services make use of sensor technologies to quantify movement, and virtual environments have been explored as a way to allow specialists to manipulate the patient's environment.

Telerehabilitation has become increasingly viable thanks to advances in communications technologies [10], but the problem with current telerehabilitation approaches is that they do not allow the therapist to work in three-dimensional space, and most systems use classic videoconferencing methods, which may not be ideal for the types of interaction required in physiotherapy. While current tools may provide outcomes that are similar to face-to-face therapy, tools that address these issues may result in a more efficient and enjoyable experience. OneSpace [6], a tool that allows multiple users to share a virtual space remotely through video, has the potential to support image-based telerehabilitation by allowing for depth relationships to be preserved during the communication (Figure 2). As it is primarily a tool for video communication, OneSpace obviously falls into the category of image-based telerehabilitation technology, but it may also be classified as sensor-based, as well as a virtual environment for therapy, since it makes use of depth sensors and places the participants in a shared virtual environment. As this tool could fit into any of the three classifications, it is important to evaluate it as a possible tool to support physical telerehabilitation.

Our approach to solving the problem with current telerehabilitation methods is to perform a qualitative study that will explore how therapists traditionally work effectively with patients, evaluate the depth and shared space afforded by OneSpace as resources in physical telerehabilitation, and we will also explore how the system might be utilized to increase the effectiveness of traditional, offline therapy. The steps we will take in this work include investigation into current methods and systems used and research currently being done, making improvements to the OneSpace design, as well as observation of the OneSpace system in use by a physiotherapist, with the goal of answering the following research questions:

- What is the nature of communication between the physiotherapist and the patient?
- How can remote communication technologies such as OneSpace address communication needs in physiotherapy?
- How might technologies such as OneSpace address the needs of the physiotherapist and patient during local, offline tasks for treatment?

In answering these research questions, the expected contribution of this work is that it will begin to guide future development of tools and processes to support physical therapy in varying capacities.

1.1 The Physical Therapy Process

To provide an understanding of the problem space, we will describe the process of conventional physical therapy. Unless otherwise stated, the information in this section was acquired during design sessions with our participating therapists. For clarity, in non-specific examples throughout this work, we refer to the physical therapist as female, and the patient as male.

Physiotherapists work with patients that have some sort of movement issue, and the goal of the therapy is to reduce disability and increase function of the affected body part [11]. This type of therapy would involve assessment of function and disability by the therapist, as well as guiding the patient in exercises that are intended to support the patient's rehabilitation. The task is one that has traditionally required colocation of the patient and the practitioner, since the interaction is fairly hands on for the therapist.

To ensure proper treatment is delivered, the therapist performs an assessment on each new patient, as well as at regular intervals to track progress. Apart from the assessment and development of a treatment plan, the patient participates in follow-up sessions that may consist of an exercise program, the therapist performing manual therapy (physically manipulating the affected part of the body), and discussions about treatment modalities that patients can do on their own (for example, applying ice to an inflamed joint). The structure of these follow up appointments is very individual, and must be customized for each patient depending on their specific needs.

1.2 Iteration on OneSpace Design

We used an iterative design process in order to improve the design of OneSpace as it relates to physical therapy and telerehabilitation. This process consists of three unique phases: 1) Investigation, 2) Prototyping, and 3) Evaluation. We started in the Investigation phase, where we learned about the latest version of the OneSpace system and discussed with therapists how it might support physical therapy. We then moved into the Prototyping phase, which consisted of the development of a tool to assist the therapist in guiding the patient using a visual guide. Finally, we demonstrated the prototype to our therapists, who provided feedback on the design of the system. The feedback from the evaluation phase was utilized in the Investigation phase of the following cycle. We went through two design cycles in total, and Figure 1 illustrates this general design cycle.

We were able to learn throughout this process that it would be valuable for the therapist to be able to manipulate the shared virtual environment in some way. The final prototype serves to demonstrate how the therapist might guide a patient by placing targets in the shared virtual space created by OneSpace, with which the patient may interact. This process and the results are explained in detail in Section 4.2.

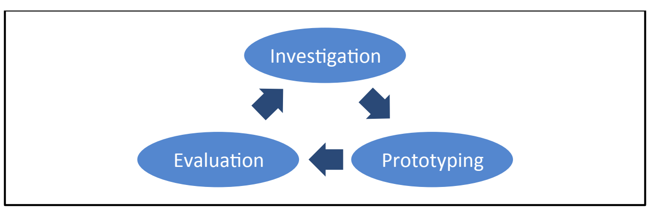

Figure 1. Iterative design process for improvement of OneSpace design, illustrating the flow and separate phases of a design cycle.

2. RELATED WORK

Since the beginning of research into Computer Supported Cooperative Work (CSCW), there has been a focus on allowing remote collaborators to share a workspace, and it has also been a goal to allow skills to be taught via these systems. While studies in physical telerehabilitation are being performed, they typically deal with more conventional videoconferencing technologies, such as pan-tilt-zoom (PTZ) cameras [13]. It seems that studies in telerehabilitation have not yet investigated the use of shared space or depth to support physical therapy remotely, which we will begin to address with this study. The following outlines some research in CSCW systems, their potential to support remote instruction, work that has been done in physical telerehabilitation, and investigations into how technology can support physiotherapy in general.

Rehabilitation using Video-Mediated Communication. Videoconferencing has become a common tool for communication with others remotely, and it has been effectively utilized in many telemedicine applications [10]. Tousignant, et al. discovered through their study with telerehabilitation after total knee arthroplasty (TKA) that physical telerehabilitation appears to be effective as an alternative to in-home visits by a therapist for rehabilitation [13]. The results of a related study indicate that satisfaction of the patients and therapists using the technology was high, and that patients' level of satisfaction was as high as those receiving traditional physiotherapy [12].

While much of the work with CSCW systems has focused on shared workspaces such as tables and white boards, the workspace that the physiotherapist actually uses is the patient, and the space that the patient inhabits. This unique type of work may require a unique tool, which allows the therapist a way to "enter" the patient's environment, and work closely with the patient within their space.

Tools to Support Traditional Physical Therapy. Exploration into how different systems could support physiotherapy is increasingly common, and these systems are becoming more promising as technology continues to advance. Nicolau et al. propose a solution to the problem of inaccurate measurement and progress tracking during assessment for rehabilitation [8]. The system they created to support therapists makes use of motion tracking technology to record a patient's movements as a skeleton visualization, which lets the therapist replay the movements later, rotate the view of the patient, and overlay a movement on a previous one for comparison. Some commercially available tools, such as DartFish or Microsoft's Kinect, may also assist in evaluation of a patient's progress in different ways, but research suggests that the Kinect is not as accurate as DartFish for motion analysis, though it is more affordable [2, 15].

Repetitive movements and exercises can help patients with motor disabilities decrease their limitations, but many patients do not perform these exercises as recommended [1]. Motivation is one of the factors that contribute to this non-compliance, so another common area of research addresses the motivation issue using technology. Kinerehab is a Kinect-based system that uses audio and video feedback to try to assist therapists and engage patients in their therapy in an entertaining way. Video capture virtual reality systems, such as the Sony EyeToy and VividGroup's GX system, have been evaluated as supporting technologies in rehabilitation, and while they are effective motivators, the inability to customize some of these technologies to the therapist's and patient's needs limited their usefulness [14].

Systems for Cooperative Work. Finding novel and effective ways to share space has long been goal of researchers in the area of Computer Supported Cooperative Work (CSCW). An early system that focused on providing a shared workspace for remote collaborators was ClearBoard, which employed a metaphor of "looking through and drawing on a big glass board" [4]. ClearBoard afforded collaborators the ability to see the actual image of their partner in the drawing space, and allowed for gaze information to be conveyed along with deictic information through hand gestures.

A tool that focuses less on workspace and more on providing users a communication environment is HyperMirror, which allows for a "What I See Is What You See" representation of a shared space [7]. This system uses blue screen technology to overlay one collaborator's image onto the video image space of another. Through observation of the system's use, the authors were able to see that real world principles seemed to apply to HyperMirror, such as respect of personal space, pointing for communication, and a feeling of physical proximity to the person in the shared virtual space.

OneSpace. The OneSpace system extends the work presented in HyperMirror by preserving the mirror metaphor, but unlike HyperMirror, OneSpace respects depth relationships between collaborators [6]. Rather than the traditional chroma-keyed implementation used by HyperMirror, which only allows one collaborator to be overlaid on the video feed of the other, OneSpace dynamically checks each pixel from all collaborators' feeds and reconstructs an image with only the front-most pixels being displayed. Figure 2 provides an illustrated example of this reconstruction.

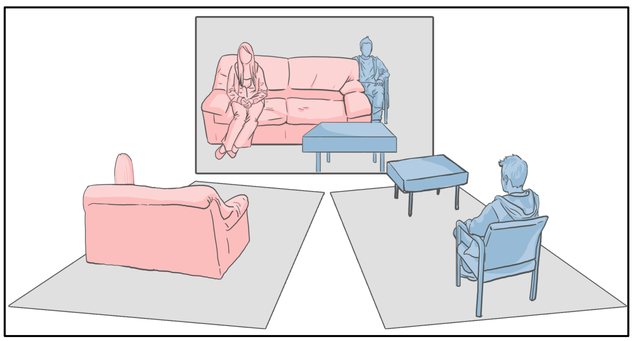

Figure 2. Image reconstruction with OneSpace [6].

Teaching Skills with CSCW Systems. Through evaluation of various CSCW systems, scenarios that involve teaching specific skills have been explored, and since physiotherapy is largely about teaching exercises to a patient, this history is important in guiding current research. For example, Ishii, et al. [3] evaluated the TeamWorkStation-2 (TWS-2) system by having an instructor provide calligraphy lessons to a student using TWS-2, which allowed the collaborators to convey drawing information, as well as gesture information.

Another system that has been used to teach skills remotely is ClearBoard, which was utilized to teach the game of Backgammon [4]. ClearBoard allowed the instructor to use gestures while monitoring this student's gaze to ensure that they were focusing on the proper space on the board. Xiao and Ishii created MirrorFugue as a tool to support remote piano instruction [16]. MirrorFugue explored the use of projection of an instructor's hands onto the student's piano in various orientations, and found that the students learned best when the image of the instructor's hands was offset just above the keyboard, with the orientation the same as the students' orientation, which allowed the student to see the instructor's hand gestures. These works are important, as they illustrate the potential for various CSCW systems to support remote instruction, and these principles may extend to physiotherapy.

3. DESIGN SESSIONS

We invited two physical therapists to participate separately in in-depth design sessions, with the content discussed in these sessions being guided by a substantial literature review. The goal of these design sessions was to make improvements to the OneSpace design, and to begin answering our research questions.

3.1 Participants

We recruited our first participant, Larry, through word of mouth. Larry then referred his colleague Alice to us, and we worked with her for the remainder of the study. Both of these therapists currently work together at a local physiotherapy clinic.

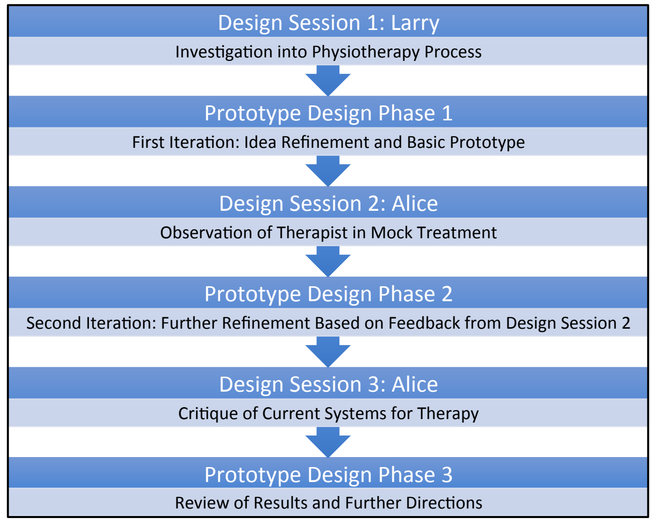

Figure 3. Important milestones in design sessions and prototype creation.

3.2 Sessions

The design sessions we participated in with the therapists were loosely structured, and were guided by the research questions we posed above. These sessions generally began with demonstrations of potential systems, including OneSpace, to support physical therapy along with discussions of the tools and their potential uses. We followed each of these demonstrations with a deeper exploration of the positives and negatives of each tool, and explored possible improvements to these systems that would make them more valuable to our therapists. The process is illustrated in Figure 3.

The design sessions each had unique goals. Having limited knowledge of the actual process involved with traditional physical therapy, the goal of the first session was to better understand how therapists currently work with their patients. This session also allowed us to get Larry's initial thoughts about how the OneSpace system might support remote physical therapy. The second session had Alice leading a volunteer in mock exercises, with the goal of further exploring how the therapist might actually use the system in practice, and this also allowed us to see how Alice's use of the system might be different from Larry's. This second session also explored how the telerehabilitation experience with OneSpace might differ from that of a conventional videoconferencing system by having the therapist use both systems separately while leading the patient in similar exercises. For the third and final session, we invited Alice to discuss her thoughts on systems being used commercially and in research to support physical therapy in varying capacities, and explored how some of the features of these systems might support therapy, as well as how some of these principles might be incorporated into the OneSpace design.

One of the software tools we discussed was a custom prototype, the production of which happened between the sessions with our participants. This tool, which we referred to simply as "the targeting system", is a standalone application that functions outside of OneSpace, and is meant to give the therapist a feeling for how the they might be able to guide a patient in a future version of OneSpace, without having to change OneSpace itself. Since changing the design of the actual OneSpace system is costly in terms of time, it is cheaper and easier to build a simple application that demonstrates the feature we would like to evaluate. This development of this tool is discussed further in Section 4.2.

4. FINDINGS

Design sessions with our participants revealed a large amount of information explaining how therapists currently work with their patients, and uncovered some of the strengths and weaknesses of these processes. In researching these practices, we were also able to explore how the therapists might make use of different technologies in order to support the process in varying capacities. Through observing the use of OneSpace by our therapists, it was clear that both had different ideas about how they would use the system to guide their patients. As an example, Larry insisted on standing in front of the patient, even when the patient was performing the exercises, while Alice stood beside the patient as she would if she were working in a mirror with a collocated patient. This example is illustrated in Figure 4. These differences in therapist practice are not examined in detail here, but would be worth studying in more depth in a future study.

We discuss design considerations as well as describe in detail the process of developing a prototype tool for assisting therapists in physical therapy. Unless otherwise noted, our design sessions with participating therapists are the source of all information in the findings.

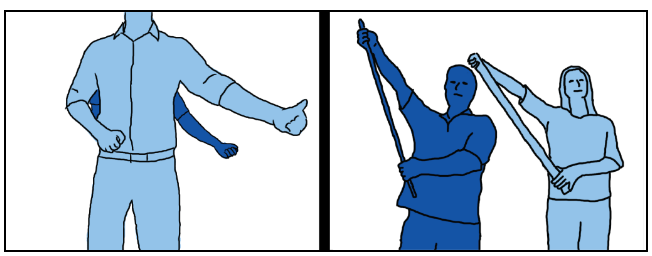

Figure 4. Differences between instruction styles using OneSpace. The therapist is lightly shaded, and patient is dark.

4.1 Design Considerations

Here we present a number of important design considerations to account for when developing tools to support physical therapy, not just as they relate to telerehabilitation, but to traditional therapy as well.

4.1.1 Types of Communication

When a therapist is teaching a movement to a patient, she will do this in one of three ways: 1) verbally, 2) by demonstration, or 3) tactilely, with her hands. These communication techniques work well in person, but certain aspects of these methods present unique challenges when it comes to remote physical therapy. While all conventional videoconferencing systems should allow for effective verbal communication, and even varying degrees of demonstration by the therapist, the ability to place hands on the patient in order to guide them is currently not possible in the conventional sense.

Through use with OneSpace, our participants felt that the system would support demonstration very well, and may even be better than the traditional methods by allowing for a type of self-demonstration. Alice believed that if OneSpace could record the patient performing an exercise, when the movement is played back as the patient exercises at home, the visual representation might prompt better recall of the exercise than seeing someone else's performance of the task. OneSpace would allow the patient to see his personal intricacies of movement and postural information conveyed at the time of the ideal exercise, so he may relearn the exercise faster and perform it more accurately than if he had to rely on his memory and a generalized document. Because OneSpace seems to support demonstration well, it may be utilized for live remote therapy sessions between in-person assessments, and this might ease the burden on certain patients.

Opportunities for Design. While videoconferencing does not allow for the therapist to put hands on the patient, the depth and shared-space afforded by OneSpace may begin to provide a sense of the therapist's hands guiding the patient. While leading her patient in a mock exercise, Alice was able to convey movement information to the patient by motioning as she would if she were guiding the patient in collocated therapy. This example is illustrated in Figure 5. In transitioning from a traditional videoconferencing condition to OneSpace, our therapist immediately noted her inability to use deictic gestures such as pointing to guide the patient the way she needed to.

In the future, one might imagine a haptic system that provides the patient with a vibration on his skin when the therapist wants him to move in a certain way. So, while this hands-on technique to guide the patient might currently be weak, some feeling of it exists with OneSpace, and future systems may be able to create a more meaningful simulation of tactile communication.

Figure 5. Instructor guides patient using hand motions, then demonstrates the proper movement.

4.1.2 Assessment and Therapist Feedback

Being able to effectively guide the patient in performing exercises is only a portion of the physical therapy process, and the therapist must be able to assess how her patient is progressing through the treatment. Some of the factors the therapist may assess are range of motion, tension, pain, strength, muscle tone, and skin qualities (tone, temperature, hair growth and tissue adherence). Some of these factors may be assessed visually, but a number of them require the therapist to be able to physically touch the patient. This problem is related to the tactile problem presented above, but rather than guiding the patient with her hands, the therapist attempts to get information from the patient's body through touch.

We learned from the initial design session that being able to place hands on the patient is important for assessment and manual therapy. The greatest limitation of the OneSpace system would be the inability of the therapist to place her hands on the patient, because much of the assessment is reading the patient with her fingers. Feeling for tension, gauging strength, feeling for temperature, and checking for tissue adherence are all important aspects of the assessment that happen with the therapist's hands. While this is a limitation, one therapist repeated stressed the idea that while not being able to put her hands on the patient was a limitation, if the patient truly cannot access services, some amount of hands-off therapy may be better than no therapy at all.

Apart from sensory feedback using the hands, measuring range of motion can be vital in certain cases:

> *For something like a total knee replacement, the surgeons are really adamant about knowing how far they are at how many weeks post-surgery, so for that I will use a goniometer and line it up correctly with the landmarks on the body, and then find out exactly to the degree. [Alice]*

The device that therapists use currently in collocated therapy for measurement of angles is the goniometer, a tool that is similar in function to a protractor. When assessing a patient, the measure may be imprecise for some cases, but others may require a high level of accuracy, perhaps to the nearest degree. Measuring at regular intervals and quantifying the improvement would also benefit the patient, whose progress improves so subtly that he can lose drive and motivation without concrete proof of his progression.

Opportunities for Design. Software such as Nicolau's evaluation system, DartFish, or a custom Kinect program could virtually perform the task of the goniometer [8, 15]. Our participants initially believed that assessment would not be possible, but after discussing some features of the software we explored during the final design session, Alice believed that if some of these features were incorporated into OneSpace, assessment may be possible in some cases.

> *For a non-complex case, yes, I think it could be possible. Someone [who is] post-total knee replacement just looking to increase range and strength. As long as you can kind of communicate with them and they're aware to observe for any infections or DVT or risk of blood clots then yes. A lot of that you can do virtually and just through communication. [Alice]*

DartFish and Nicolau's system provide a high degree of accuracy, and while the Kinect may not be capable of this type of accuracy, the relatively low cost and ease of use make it an attractive potential tool in assessment for physiotherapists.

4.1.3 Memory and Instructional Aids

With a patient learning multiple exercises in a session, it can be difficult for him to remember how to correctly perform the movement when he works on the exercise between sessions. While not performing his exercises may be detrimental to a patient's recovery, performing his exercises incorrectly may be a more serious issue, since this can aggravate his condition. Since performance of an exercise is temporally fleeting, it is important that the therapist is able to supplement the experience for her patient with instructional aids to assist in jogging his memory while he works between sessions.

The most common instructional aid provided to patients by therapists is a printed document consisting of images of someone performing the exercise, with a written explanation of how to perform the exercise. While using this document, patients still make mistakes, especially older patients, so it seems that this document is not conveying enough information for the patient to be able to accurately perform the exercises.

Opportunities for Design. One possible, though currently unimplemented, feature of OneSpace would be the ability to record the patient performing his exercises, and being able to play this recording back with depth information. In comparing this possibility to the current instructional aids in use, a recording of the patient would be more useful, and the patient seeing himself performing the exercise may serve as a better reminder of the movement's proper execution than the printed document.

Nike+ Kinect utilizes a virtual instructor that teaches the user how to perform specific exercises, and this instructor also performs exercises while coaching the user [9]. While she initially believed that it would be necessary to be live with the patient during remote follow-up sessions, after seeing the capabilities of Nike+ Kinect, Alice thought a system that could correct the patient as Nike+ Kinect does would be perfect if it could be customized for the patient. Combining the recorded version of the patient doing the exercise properly with the ability of the Nike+ Kinect to correct the patient may result in better treatment outcomes, and this could be worth exploring further.

4.1.4 Customization of Treatment

As with any type of medical treatment, patients respond uniquely to different interventions, and the therapist must tailor the therapy to the individual patient. In order to provide effective treatment, the therapist needs to be monitoring the patient and responding to their needs.

> *As a therapist, you have to monitor your patients. You have to be kind of sensitive to what type of day they're having, how irritable they are that day, if they're responding well to a given exercise, or if you should just totally abandon it, because you can have a protocol and this might be the next exercise that it says to teach them, but if they're not responding well to it, are you really going to hammer it in? Not really. [Larry]*

While general versions of the exercises may be suitable for the majority of patients, there are situations in which the therapist must change how the exercises are done to suit patients with specific needs. A patient with a broken arm that limits their movement will need a variation on certain exercises that the general population would do, and the therapist needs to be able to address these issues when developing a treatment plan.

The customization issue has been identified as a problem in past research. Software such as Nintendo Wii games have been found to be useful in some capacity because of the amount of engagement they provide, but an inability to grade the difficulty to the patient's abilities, which may be notably restricted, is a major limitation [5].

Opportunities for Design. Allowing the patient to perform exercises with a video representation of the instructor or themselves appears to be a valuable feature. Simply recording the general case and making it available to the patient may not be ideal, however, since they may have unique needs. By giving the patient the ability to reference a video representation of the exercise based on a recording of his own movements, he would be

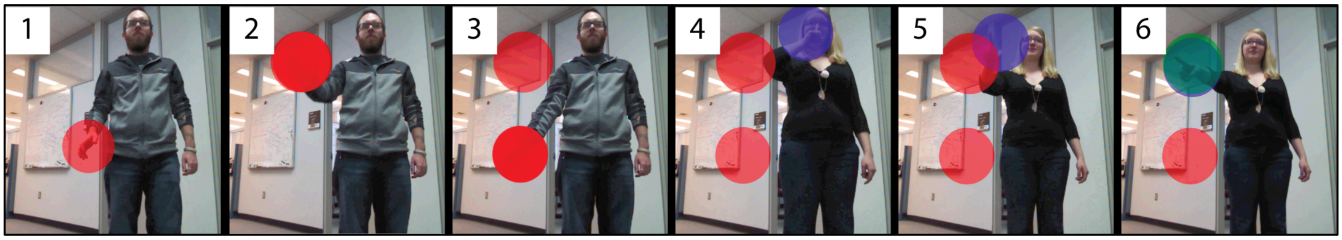

Figure 6. (1-3) Instructor placing targets. (4-6) Patient interacting with verbal guidance from instructor.

receiving a custom version of his exercises, and this is more beneficial than the generic printout the patients currently receive.

4.1.5 Video Resolution

Since physical therapy can involve any part of the body, it is important that the therapist is able to clearly see fine details on her remote patient when performing telerehabilitation. The relatively low resolution of conventional videoconferencing technologies may be a limiting factor when attempting to perform certain types of therapies, and one of the main issues with OneSpace is the low resolution of the video image.

While the resolution provided by the Kinect hardware is relatively low, the image reconstruction is notably troublesome in OneSpace, resulting in extreme pixilation and rough, blocky edges. The therapists initially believed that the resolution was fine for their purposes, but certain issues were uncovered when Alice attempted to lead her patient in some finger exercises that were possible with traditional videoconferencing. The conventional videoconferencing setup allowed the therapist and patient to present their fingers close to the camera for the other to see, but OneSpace's limited visible range did not afford participants the opportunity to engage in this activity, and the finger seemed to disappear in the visible range.

These problems may currently be substantial, but the resolution issue is one that will sort itself out over time. As connections become faster and resolution of commercial depth cameras such as Kinect becomes higher, this will cease to be an issue.

4.2 Targeting to Guide the Patient

One of the goals of our work is to make improvements to the OneSpace system, with the objective of making it better suited to support physical therapy and telerehabilitation. In facilitating the design sessions, we were able to get valuable feedback from physiotherapists about how software may augment their process, and from this information, we created a prototype tool to assist therapists in guiding patients in remote exercises. This prototype can actually be used by therapists and patients, and represents a significant feature that makes the remote therapy experience richer by allowing for a more effective use of depth. As a prototype, the motivation for the creation of this tool was simply to convey the idea to potential users of how this feature might be incorporated into OneSpace. The prototype exists outside of OneSpace, and can only be used locally, but by demonstrating this system to a therapist, she was able to imagine how she might be able to use this type of feature to guide a patient in exercising remotely with OneSpace.

4.2.1 Design

Initial Design Ideas. During our first design session with Larry, we had prepared a number of initial thoughts about what types of improvements we might make to the system, based on information gained from the literature review. These initial concepts shared similar themes: 1) Allowing the therapist to manipulate the patient's environment in a meaningful way, 2) Allowing the therapist to gain additional information from the patient, such as joint angles to assess range of motion, and 3) The ability to record oneself with depth information for playback and interaction later. Based on Larry's feedback, as well as a desire to explore the potential of OneSpace as a tool for virtual reality telerehabilitation, we chose to explore features that would allow the therapist to manipulate the patient's environment.

Design Goal. Because the therapist is limited in guiding interactions by remote communication, our goal in designing this system is to allow therapist to communicate instructions more effectively. With this tool, which we call "the targeting system", the therapist is able to define certain extents that she would like the patient to move a specified joint between, and this essentially extends her ability to communicate verbally and by demonstration. The therapist can define the constraints on the movement by performing it herself, and then instruct the patient verbally in moving along the path she defined.

Description of Function. The goal of the tool is to allow the therapist to place actual targets, like small bull's eyes, with depth information into the patient's virtual space, with which the patient can interact. When the proper joint of the patient makes contact with the virtual target, the target changes color, providing necessary feedback to the patient and therapist, indicating the correct joint placement. The therapist controls the targeting system entirely with voice commands, and this system has two separate modes, a setup mode and an interaction mode. In the setup mode, the therapist is able to set targets in the virtual space using only voice commands and her right hand. The right hand acts as a cursor, and a red target locks to the therapist's hand when she is in the setup mode. As she moves her hand closer to the camera, the circular target grows in diameter, and shrinks as she pulls away. With the "set target" voice command, a semi-opaque target is semi-permanently placed in the space the cursor is currently occupying. With the commands "clear last" and "clear all", the therapist can remove individual targets and all targets on the screen respectively. With the "stop target mode" command, the therapist exits the setup mode, and the interaction mode is engaged.

When a patient is in interaction mode, his right hand becomes a cursor, just as the therapist's hand did in the setup mode, but the patient's target is now blue. As the patient's hand moves through space, the target is dynamically resized as the therapist's was. When his target matches the position and size (and therefore depth) within a given tolerance of one of the therapist's set targets, the therapist's previously placed target changes to green. This change in color indicates to both the patient and the therapist that the patient has properly positioned the joint. A use scenario is illustrated in Figure 6.

4.2.2 Implementation

Technical Details. The targeting system is a C# WPF application that was created in Visual Studio using the Kinect SDK v1.6, with the Kinect for Windows hardware. While we attempted to use the system with the Xbox Kinect, the system ended up being unusable since the amount of noise is greatly increased in the Xbox version of the hardware, and interacting with targets becomes unreasonably difficult.

Built-in functionality allowed us to track the position of the user's hand in three dimensions using the skeleton tracking of the Kinect SDK. Targets are standard Ellipse objects, and when the target is placed in the scene, it is added as a child of a Canvas that holds all of the current targets. In order to conserve depth information, each target has a depth value associated with it, and the size of the target is calculated using a linear function based on the maximum target size, minimum target size, maximum depth and minimum depth, all of which are variables that may be altered based on the therapist's preferences. Each of the targets also has a bounding box based on the size of the target and a depth tolerance that can also be altered by the therapist, and as the patient's joint collides with this box, the color of the set target is changed to green.

Finally, the system is controlled entirely with voice commands, which are handled with the Microsoft Speech Platform SDK. The speech recognition engine is always listening for commands, and when it recognizes a valid speech command, an event handler determines what the action should be.

Limitations. As a prototype, this system only tracks a single joint, which is not ideal in practice since an exercise in physiotherapy may require a number of different joints to be positioned in a specific way. The use of voice commands to control the system also causes issues, because there are a number of false positives in practice. Since the therapist needs to guide the patient using verbal instructions outside of the voice commands, issues such as targets being inadvertently placed and removed, modes being switched, and the program closing unexpectedly exist in practice.

4.2.3 Feedback

We received feedback from the therapists during our design sessions, so this allowed us three separate discussions about how the targeting system might be designed. The feedback provided by Larry in the first session narrowed our focus to manipulation of the patient's environment. During the second session with Alice we were able to demonstrate to her how the targets may be placed in the virtual space, but had not implemented the interaction mode at that time. Alice shared her thoughts about the system and provided examples of how she might make use of such features if they were incorporated into OneSpace. During the third design session, we provided a demonstration of the latest iteration of the software in use, referencing an example of stroke therapy we discussed during Alice's critique in the second session. Suggestions for improvement were the ability to track multiple joints simultaneously, and to allow the therapist to view a motion path that might aid the physiotherapist in qualifying movement between targets.

4.2.4 Future Iterations

We would like to continue iterating on the design of the targeting system, as it appears to be a promising way for a therapist to guide a patient in specific exercises remotely.

Depth Representation of Targets in OneSpace. One of the most important changes we could make to the tool would be integration of the targeting system into OneSpace. This would allow us to observe how therapists would actually use the system in a remote therapy scenario, and would allow for a depth representation of the targets. The tool currently displays the targets in front of the users at all times, but with the OneSpace system, the targets could respect spatial relationships between users and targets the way that it does between participants currently.

Tracking Multiple Joints. Another feature we would like to explore in future iterations is the ability to track multiple joints, which would allow support for more complex movements than the system currently handles. This would be a substantial change, and proper implementation would be difficult, but the results of our design sessions show that it would be valuable. The biggest issue with implementing a feature like this is handling different body types. If, for example, the therapist is tall and wide, and the patient is short and thin, the absolute joint positions would vary greatly, so the system would need to be able to scale the targets to the patient's body shape.

Visual Indication of Movement Path. Simply moving between targets in space is only a portion of the issue in physiotherapy, and how the patient moves between points is important. We would like to implement a feature that allows the therapist to see a visual representation of the path the patient is taking between targets, and may also explore how we might quantify this path information.

5. DISCUSSION

Nature of Communication. From our design sessions and findings, we were able to learn about the most important aspects of communication between the therapist and patient in physical therapy. The three important methods for communication of instructions to the patient, which are verbal, demonstrative, and tactile, must all be considered when designing to support physiotherapy, since different systems support these types of interactions with varying levels of success. For example, a video representation of a person performing an exercise provides better demonstration of an exercise, and the shared space provided by OneSpace allows for more of a feeling of hands on than traditional videoconferencing does. Therapy is also guided by actively reading the patient and their needs, so the therapist must be allowed to receive specific information as it becomes necessary, and this is received mainly through touch, which presents unique challenges for design.

Tools for Remote Therapy. As we discovered through learning about the nature of communication in physiotherapy, so much of the process involves the therapist actually being able to touch the patient that fully remote therapy would be impossible with currently available technology. Our findings suggest, however, that limited assessment may be possible with proper technology in simpler cases, and it appears that a tool such as OneSpace might allow the therapist to engage with the patient remotely between full assessment sessions. This allowance for some remote follow-up sessions may lessen the burden on a patient that has a hard time accessing services for some reason. Since research suggests that telerehabilitation between assessments is possible using a traditional videoconferencing setup [13], it is reasonable to assume that a system like OneSpace can support remote therapy in the same way, as long as it can zoom in on points of interest and allow for the same resolution as other effective systems. Any points of differentiation for OneSpace as it relates to traditional videoconferencing systems should be improvements, so the interaction facilitated by OneSpace should be at least as effective as, and possibly richer than, these traditional systems.

Tools for Local Therapy. While OneSpace is primarily a tool for remote communication, small changes in the design of the system would allow users to playback previously recorded depth videos. Our findings suggest that this might allow for more meaningful demonstration when the patient is attempting to perform exercises outside of sessions with the therapist, and this type of recording as an instructional aid would be better than what therapists currently use in practice. Changes to the design of OneSpace may also incorporate valuable offline features to increase motivation, allow the therapist to track progress and compliance with exercises, and allow for useful customizations to the treatment plan.

6. CONCLUSION

While tools for videoconferencing may not make the physiotherapy process entirely remote, and a therapist may always need to meet with and assess the patient in some way, our results suggest that it may be possible for certain technologies to at least aid in the process. Since motivation and proper execution of exercises are currently problems with collocated therapy, it would be valuable to incorporate features to address some of these difficulties when designing new tools for therapists.

Our work is notably limited by its small scope, and while in-depth discussion with practicing therapists is valuable, both of these therapists were relatively young and worked in the same clinic, so the perspectives we gained may be limited. Varying the experience and specialization of participants would broaden our understanding of both the nature of the communication in therapy and how software might support physiotherapy. We also focused our work around OneSpace, so perspectives primarily relate to how this specific system might work in practice.

In the future, we hope to continue this work while addressing some of the limiting factors above. We will continue iterating on our software design, and would be interested in evaluating it by utilizing a larger group of therapists. A significant aspect of this would be to further understand some of the patient motivation and compliance issues, and compare the effectiveness of different instructional aids for patient work between sessions. The therapists in our study made use of OneSpace in very different ways, so it would also be interesting to explore how more therapists would use the system. As demonstrated in this work, video communication tools appear to be promising supportive technologies for physical therapy, and we are excited to explore these applications further.

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