Empowering Patients to Perform Physical Therapy at Home

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Abstract— **In this paper we address the problem of patient adherence to physical therapy using a sensor-enabled virtual reality gaming interface that motivates users to complete their exercises while collecting quantitative data. The system also allows the therapist to monitor and interact with patients remotely providing reinforcing feedback and support with the CollaboRhythm care delivery platform. The data collected with this system enables the therapist and the patient to make informed decisions about patient treatment and exercise regimens based on the patient progress. The system is capable of supporting a wide array of rehabilitation scenarios with remote collaboration. A knee replacement scenario was tested with an experimental protocol involving 16 healthy participants. The results show both quantitatively and qualitatively that patients can learn intuitively to perform their physical therapy exercises on a remote environment without further human intervention.**

I. Introduction

Patient adherence to recommended physical therapy home exercise programs is relatively poor [1]. Jette reported that 45-60% of patients with arthritis do not comply with prescribed exercise programs [2]. More recent studies suggest that it can be as low as 24% [3]. Non-compliance of the physical therapy has traditionally been defined as a failure by patients to follow advice. Some reasons for the lack of compliance include: the absence of positive feedback, the barriers that patients perceive and encounter, and the degree of helplessness they experience [4]. These barriers can be partially due to the difficulties on interpreting classical paper instructions, in addition to the little clues that traditional physical therapy shows on the short-term benefits of the exercises. In order to achieve higher adherence to physical therapy we present a rehabilitation system that runs on a tablet computer. This setup enables patients to learn rapidly the exercises, motivates them towards the goals during the performance and empowers them to be more in control of their physical therapy regime and results. We have implemented and tested features such as gaming exercises and continuous activity monitoring that were determined to be important in the success of this project based on previous research [5]. An experimental study involving 16 participants was run to test the current setup. Each participant underwent a series of 6 knee rehabilitation exercises repeated in two sets using a mobile platform without any instruction or previous training. Results show a significant improvement from the first set performance to the second one, meaning that participants were able to learn from the system how to maximize and improve their exercise performance.

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II. Materials and Methods

A. Architecture

The system consists of a central server running at the research facility where patients requiring rehabilitation can remotely connect through their tablets. The main server keeps track of the patients' performance over time, and their physical therapy regimes by using the Indivo X health record database [6]. The client is a UNITY virtual reality game connected to motion capture sensors that interacts through the network with the central server.

This architecture enables features of social gaming in which the community can contribute to the exercises pool by recording and adding new exercises. Furthermore, it implements real-time collaboration among multiple players such as family and patients performing their therapy together in a single game; or for a physical therapist to remotely demonstrate the proper technique while observing the patient's movements in real-time. We believe that the social support will be critical in improving patient outcomes.

Furthermore, leveraging the open-source health care delivery platform CollaboRhythm [7, 8] built at the MIT Media Lab, the system allows physical therapists, patients and relatives to work remotely as a team to formulate therapy plans, discuss progress, and adapt to obstacles (Figure 1).

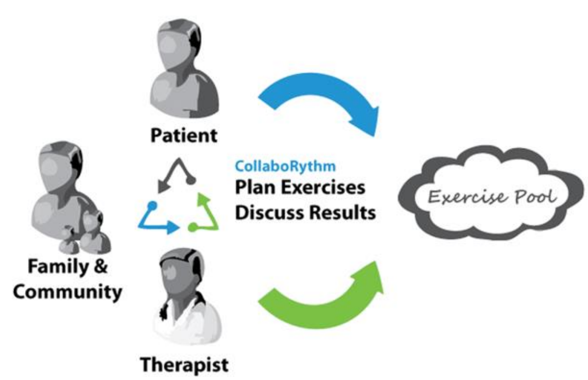

Figure 1. *Schema of the user relations enabled by the system.*

B. Gaming Features

Several features that were determined to be important in the success of this project were implemented based on previous research [5]. These features include the support for gaming on mobile devices and continuous activity monitoring but two other important aspects were identified:

- Trainer: the figure of the trainer showing the exercise has a high impact on the performance of the therapy. Mirror neuron experiments have shown the relevance of observation and imitation on motor learning from a very early age [9, 10]. To enhance the learning by imitation the game has two avatars in the scene, one avatar performs the exercises as a model for the patient to follow and learn the exercises when at home. The other is the virtual representation of the patient.
- Scoring: the rehabilitation app implemented a game with a simple performance ranking that was used in real-time to evaluate the patient's precision with respect to the prescribed exercise. If the exercise was done appropriately, i.e. knee angles achieved, as well as the velocity of the exercise, the score would be higher. This will motivate the patients to do better.

C. Apparatus

The motion of the knee for the experimental study was collected in real time using a three axis positioning miniature wireless accelerometer called wocket [11, 12]. The wocket sensors are safe and cause no discomfort. In continuous mode, they stream real-time 3-axis (10 bit/axis) accelerometer data to the tablet at 40Hz, permitting low-latency processing and activity-based feedback if desired. The wockets are open source as described in [12]. The real-time motion tracking it's also important to generate a real agency illusion over the avatar [13].

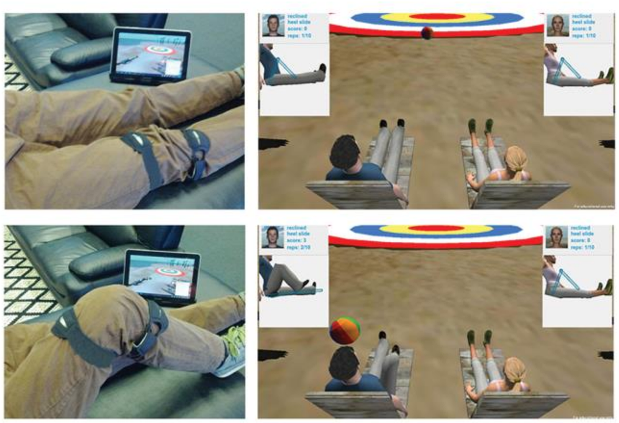

Figure 2. *Heel Slide Exercise. As the subject moves the knee from straight to bent; the gauge shows the knee angle. When the subject straightens the knee, the avatar kicks the ball to the target. Another ball will then roll from the cart for the next repetition.*

The physical therapy game was programmed in UNITY, and ran on a Samsung Galaxy Tab with a 7'7 inch screen. The wockets and the tablet were connected through Bluetooth. From the 3-axis data the real time movement of the knee was extracted. That information was used to move the avatars' leg in the videogame (Figure 2).

D. Experimental Protocol

Sixteen healthy participants (8 men and 8 women) aged: 26.18, std: 3.74 were recruited to participate in this study. All participants were contacted via the e-mail list from the MIT Media Lab and signed the informed consent following the ethical principles of the Declaration of Helsinki. The experimental procedures were approved by the Committee On the Use of Humans as Experimental Subjects (COUHES-MIT), and all the experimenters involved in the study had undergone the corresponding training course from the same committee.

Once the participants entered the laboratory area, we helped them to place the wockets in the correct positions around the thigh and around the lower leg. Then the participants were invited to sit on a padded examination table while the tablet computer was positioned on a pedestal within reach. The participant was then instructed to follow the on-screen instructions in order to perform the physical therapy. Participants executed the exercise protocol as if they were performing the exercises from home. The protocol was comprised of 2 sets of 3 potentially familiar and 3 unfamiliar exercises. Each exercise included 10 repetitions. The potentially familiar exercises included: semi-recumbent heel slides, sitting knee extension-flexion, and a straight leg rise extracted from the rehabilitation protocols for *Knee Arthroscopy Rehabilitation,* publicly available at the Massachusetts General Hospital, Sports Medicine, Division of Orthopedic Surgery. The unfamiliar exercises involved 3 combinations of hip flexion and knee extension exercises. Before starting the game participants were given paper intructions only for the familiar exercises.

In the game, there was a "virtual trainer", an avatar that demonstrated the execution of the current exercise. Our hypothesis is that patients can learn totally unfamiliar exercises just from observation, as well as improve the performances on the ones they are familiar without further human intervention. Subjects completed the exercises in random order as presented on the tablet screen. It is important to note that all of the exercises are less intense and have less impact than normal walking. As a result, they present minimal risk to the subjects.

E. Data Collection

We wanted to collect both qualitative data from questionnaires and quantitative measures of their ability to learn the exercise. For that matter, their improvement in execution of the exercises from set to set was evaluated. We considered the average performance of the exercises during the first set (FS) versus the second set (SS) for all participants. The performance was calculated as the average score accomplished during the game over the ten repetitions of each exercise. The score responded to an equation where the 100% would be a zero deviation of the target knee angles for each repetition. The score was also modulated by timing, when the repetition was executed too quickly or slowly compared to the prescription; deviations in the speed of execution could penalize the score. The data from the exercise protocols was later analyzed to determine how capable the subjects were of completing the exercises.

Upon completion of the exercise protocol, the subjects removed the wockets and completed a 10 points likert-scale questionnaire to report about their experience.

Participants rated their level of agreement with the following statements after their experience:

Pain perception: "Rate the pain you feel in your knee now" (Q1). This question was answered before and after the experiment.

Interactions: "The interactions with the environment felt natural" (Q2).

Attention demanding: "I could concentrate on the assigned exercise" (Q3), "I had to think about the mechanisms (sensors and tablet) when performing the exercises" (Q4).

Learning: "The program enabled me to improve my performance" (Q5), "For the unfamiliar exercise, this program helped me learn" (Q6).

Control: "I was able to control the movements of the avatar's leg in the game" (Q7), "There was a demonstrator showing me the exercises" (Q8), "The avatar that represented me was on the left of the screen" (Q9), "I prefer not having a demonstrator in the scene" (Q10).

Usability: "I can perform the entire program on my own at home without help" (Q11), "I prefer this system over written home exercise instruction" (Q12), "Overall, I am completely satisfied with this experience" (Q13).

Time perception: "How long do you think the session took?" (Q14), "During the session, did you ever feel you lost track of time?" (Q15).

Furthermore there was one more open question for the subjects to answer: "Do you think this system would make you want to do the exercises?" (Q16). This would provide additional feedback about the usability and potential of the system.

Overall, the questions address different aspects related to the main features of the game in terms of learning, usability, attention demand, interactions, agency, time perception and pain perception. The scores went from 1 totally disagree to 10 totally agree with the statement.

III. Results

A. Questionnaire

The scores on the questionnaire as well as the statistical analysis of the corresponding questions using no parametric test (Wilcoxon sum ranks) show the following results:

Pain perception: Participants rated their levels of pain *Before* (mean=1.187, std=0.136) and *After* (mean=1.187, std=0.100), no statistical differences were found; the therapy did not induce more pain into the participants' knees.

Interactions: In general participants found the interactions with the game quite natural as they scored 7.875 out of 10 (std=0.417, Q2).

Attention demanding: When asked if they could concentrate in the exercises, participants rated 9.125 (std=0.230, Q3), on the other hand when asked if they had to put much attention into the mechanisms of the game, they scored 3.437 (std=0.652, Q4). There is a significant difference (Z=-3.45, p=0.001) between both scores, which means that the attention was on the exercises rather than in the apparatus. The therapy game were intuitive enough.

Learning: When assessing the learning capabilities of the game the patients rated in 8.500 (std=0.447, Q5), and 9.187 (std= 0.261, Q6) each question out of 10. Making pretty clear that they believe the program helped them to improve their performance, also for the unfamiliar exercises.

Control: The participants rated the following questions: Q7 with an 8.375 (std=0.301); Q8 with a 10 (std=0); Q9 with an 8.8125 (std=0.571). All of them have high scores which validates that the participants understood the game therapy working; a low score would have meant that the participants could not understand the game. And would not rather have the therapy without the virtual instructor in the scene with a 2.625 (std=0.539, Q10).

Usability: When tackling usability questions the participants stated that they could be able of performing the exercise therapy at home without help with a 9.375 (std=0.386, Q11); they prefer it over written home exercise instruction with a 9.812 (std=0.136, Q12), they were satisfied with the experience with an 8.937 (std=0.295, Q13).

Time perception: Participants reported that they lost track of the time 8.187 (std=0.975, Q15). However, no significance was found when comparing their time guess (19.187 minutes, std=1.681) versus the real time expended doing the therapy (18 minutes, std=0.758 Q14). Therefore participants did not really lose track of time while playing.

B. Motor Actions

A part form the qualitative data from the questionnaire we wanted to quantitatively measure the ability to learn. For that matter, we considered the average performance of the exercises during the first set (FS) versus the second set (SS) for all participants (Figure 3).

Both populations showed a Gaussian distribution when undergoing the normality test: FS (mean=41.38%, sd=9.34%, Shapiro-Wilk=0.337), SF (mean=44.75%, sd=8.86%, Shapiro-Wilk=0.447). We further analyzed the data using a Paired samples T-test that showed a significant difference (p=0.045, T=-2.215, df=15); meaning a clear improvement of their performance from FS to SS.

When analyzing this improvement by type of exercise, familiar and unfamiliar, we do not see a significant greater improvement in the familiar (mean=4.47%, sd=7.54%, Jarque-Bera=0.375), than in the unfamiliar exercises (mean=1.85%, sd=7.55%, Jarque-Bera=0.408), difference (p=0.258, T=-2.13, df=15);

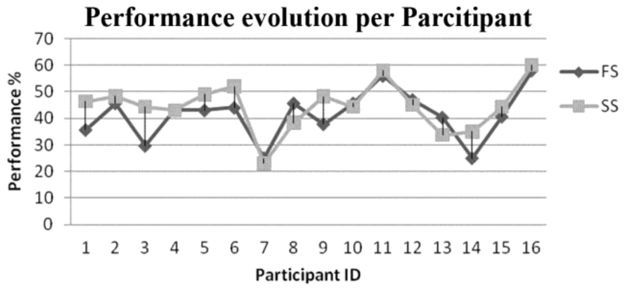

Figure 3. *The performance evolution. For each participant the FS (dark gray diamonds), vs the SS (bright gray squares). We can observe how participants generally improved their performance on their SS. Further statistical analysis showed that this behavior was normally distributed over all the participants and there was a significant improvement.*

These results show that participants were able to learn and improve only by doing the exercises with the tablet, without further human intervention in both the familiar and the unfamiliar exercises.

IV. Conclusion

The current study implemented and tested a complete rehabilitation system in a control scenario with healthy participants. To first evaluate the prototype we conducted an experimental study, explained in previous sections, where participants underwent a series of 6 exercises repeated in two sets.

Results showed a significant improvement from the first set to the second one for both the familiar and the unfamiliar exercises, meaning that the system enabled the participants to learn, while maximizing and improving their exercise performance. Further questionnaires explored the participants' experience. We found that the game mechanisms were not demanding excesive attention, allowing the participant to be focus on the exercises. Participants found the interactions with the therapy program natural and intuitive. They all considered that the system helped them learn the exercises and improve. Finally they all were sure that they would be able to perform the whole therapy on their own at home. We can conclude that the system has been proven usable as all of the participants were able to start, follow and finish the whole therapy on their own without external intervention.

Future studies will include longitudinal randomized controlled trials of patients after knee replacement surgery and compare the results of patients using the system to those receiving standard of care. More extended testing on patients will be required to further demostrate the efficacy of the system in old population at home.

We believe that the rehabilitation system that we have proposed has the potential to significantly improve patient outcomes, efficiency and cost-effectiveness of physical therapy. This system could be placed into market in the near future and contribute to increase patient adherence to physical rehabilitation at home. With such a system the physical therapist will make shared decisions about rehabilitation goals with the patient, the patient will perform the exercises through the game interface at home, allowing the physical therapist to remotely monitor progress. Furthermore, the patient and the physical therapist will be able to work together as a team to advance the program as appropriate.

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