Designing an In-Home Scalable Robotic Arm and Tablet Gaming Suite for Hand Function Rehabilitation for Neurological Disorders

A. Research Problem

The objective of the research is to examine the impact of a virtual reality experience on at-home wrist and hand function rehabilitation exercises for people with neurological disorders. Cerebral palsy is a debilitating neurological disorder that has the potential to permanently damage a person's body movements and muscle coordination [1]; however, cerebral palsy patients who participate in physical therapy sessions, a common treatment for a motor disability, may be able to regain, or retain, some motor function. Unfortunately, patients undergoing physical therapy commonly exhibit pain and boredom with their rehabilitation regimen, which studies have shown decrease a patient's participation in physical therapy and therefore lengthen recovery time. Furthermore, these studies demonstrate that physical therapy that keeps the patient engaged is more likely to shorten patient recovery time by helping that patient maintain motivation to participate in physical therapy sessions [2]. Robotic aided therapy is a new technology that has shown promising results facilitating motor learning in rehabilitation [3]. Children are especially excited about using robotics, toys, and games to complete therapeutic motions. However, existing systems are large, heavy, and expensive. Another problem with these systems is that they are created to be one-size-fits-all. Most are created to fit the average adult male, but allow for some adjustment to tighten or loosen the device. Unfortunately, children are significantly smaller than the average adult male, which does not allow these therapy options to be feasible for children. Currently, there is no known exoskeleton arm with these therapeutic capabilities specifically designed to be compatible with the arm characteristics of children.

The objective of my research is to design an innovative therapy device that customizes the learning experience for children with cerebral palsy by combining a passive robotic therapy device with an adaptive gaming suite that alters the interaction in order to best fit the needs of the user. Physical therapeutic exercises are commonly prescribed to individuals with motor disabilities with the goal of increasing proficiency of a motor skill. During the physical therapy process, individuals will usually practice once a week with the assistance of a clinician and six days a week in isolation. When practicing exercises in the presence of a skilled clinician, an individual receives several benefits including: (1) real-time feedback on accuracy of motions; (2) real-time adaptations to an exercise plan that accommodates the client's skill level and performance; (3) social interactions that increase engagement; and (4) positive feedback that increases morale. These benefits are not realized by the client when practicing exercises in isolation, causing clients to struggle with complying with therapeutic regimens at home. This lack of support in the at-home environment often causes clients to struggle with complying with therapeutic regimens at home. To address the needs of this target demographic, our goal in creating the therapy device first involved designing a robotic exoskeleton coupled with an adaptive rehabilitation gaming suite that encourages therapeutic motions. By conducting a number of participant studies, we have been able to verify the system's ability to encourage accurate therapeutic motions while increasing participant engagement. Our next set of goals involves implementation of a learning model and adaptive feed-back algorithms that monitors performance of the user based on a normative model of motor learning and provides customized feedback through game adaptation to ensure the user achieves their optimal performance for learning. Preliminary results have shown that we can maximize long-term performance by adapting the interaction based on current performance. The final system will be validated with children with cerebral palsy in a long-term study over the course of several months to ensure the trends that have been seen in able-bodied participants also occur in our target population group.

B. Research Proposal

Preliminary Work

Previous studies on persistence in physical therapy programs suggest that subjects interacting with a gaming system that utilizes a robotic exoskeleton arm often remain more engaged in the exercise routine [4]. Further research shows that patients who are engaged in their therapy sessions reach peak performance faster, retain skills longer, and are more likely to complete their rehabilitation regiment [2]. Given these encouraging findings, the focus of this project is to extend previous efforts by increasing engagement and the population who could benefit from this technology and to utilize this technology for novel applications.

This project commenced research during the Fall 2014 semester. Our previous research goal was to design a robotic exoskeleton and tablet gaming suite that promotes engagement and productivity in at-home therapeutic exercises. To achieve this goal, we created a scalable robotic exoskeleton that communicates via Bluetooth with a tablet and acts as a video game controller. We also created a suite of fun and engaging tablet game that facilitates therapeutic wrist exercises. An image of the resulting system with one of the video games is shown in Figure 1. The model of the exoskeleton can be scaled to fit the arm of any child and quickly 3D printed with their custom measurements.

Figure 1. Therapeutic wrist exoskeleton connected via Bluetooth to a tablet that contains therapeutic games.

Proposed Design

Classification of Task Difficulty

In order to create a serious gaming environment where the task difficulty adapts in order to best fit the needs of the user, we must first quantify and classify task difficulty. As a baseline, user performance from the game Guitar Hero will be analyzed in order to classify the difficulty of various target patterns. Neural networks will be used to classify sub-patterns within a level of the video game for task difficulty. We will use these patterns with defined difficulty in our adaptive feedback algorithm and learning model.

Adaptive Feedback Algorithm

One of the greatest benefits of practicing therapeutic exercises with a clinician is that the clinician is able to give their clients real-time feedback. The clinician is able to access the client's engagement as well as performance and adjust the task in order to increase engagement during the session as well as overall performance. However, when clients practice their therapeutic motions at home, they do not have any means of receiving feedback. Thus, clients regularly struggle with maintaining high levels of engagement and performance when practicing in isolation during at home therapeutic exercise sessions. Technologies exist to aid clients with the at home portion of their therapy; however, the technologies that are currently on the market do not possess the capability to automatically give real-time feedback to the users. Therefore, we will develop an adaptive control algorithm that is constantly measuring the performance of a user and autonomously adjusts the difficulty of the gaming environment in order to increase user engagement as well as to promote expedited learning of the motor task. To enhance motor learning, this algorithm will incorporate a lead-lag model in order to customize the interaction through assessment of the user's performance. Lag quantifies the negative difference between an optimal movement and the user's actual movement, while lead quantifies as a positive difference. If the user is identified as lagging behind the intended path, the therapy protocol should be adjusted such that the user is allocated more time to reach the intended target.

Learning Model

In order to further encourage expedited learning of motor tasks, we plan to implement a learning model into the adaptive game. When learning any task, a learning model can be used to project the progress of learning. The shape of this model is generally an S-shaped curve, in which the learning initially occurs at a slow rate, accelerates quickly, and then plateaus once the task is mastered. Parameters of this model, such as the height of the plateau, the location of the learning acceleration, and the rate of acceleration, vary largely from person to person. However, a general curve can still be used to estimate performance of an individual and to compare performance between individuals. Therefore, we plan to incorporate a learning model into our games to allow us to: (1) predict how the user should be performing during each session, and (2) predict how much skill is forgotten if the user takes an extended break from their exercise regimen. As the user completes exercise sessions with our system, we will be able to collect greater numbers of performance data points and, therefore, create a more accurate individualized learning model. Therefore, these performance projections will allow for more accurate starting conditions with long-term use of the system.

Evaluation

The research team plans to enroll healthy individuals and children with cerebral palsy in an IRB-approved study. Participants will be asked to complete a 4-week intervention, during which they will be asked to play the virtual reality game for 30 minutes a day, 3 times a week. Participants will be broken into 3 groups: (1) a group that plays a game with constant difficulty parameters; (2) a group that plays the games with adaptive difficulty parameters that follow the learning model; and (3) a control group that completes exercises instead of playing games. A control group will be taught wrist and hand exercises and will be instructed to complete those at the same frequency. Wrist and hand movement data will be collected during all interventions as well as survey questions after each session. In addition, a clinician will assess their hand and wrist motor function before and after the intervention.

The team's hypothesis is that all groups will make improvements above their baseline measurements. The team hypothesizes that the group that exercises with the adaptive game will see the most improvements. The team believes that this will occur because this will allow the rehabilitation to allow optimum practice conditions, allowing for optimal learning of the task. The team hypothesizes that the group that plays the adaptive game will report greater levels of enjoyment and engagement, since the game will consistently be appropriately challenging.

References

[1] "NINDS Cerebral Palsy Information Page." *National Institute of Neurological Disorders and Stroke*. National Institute of Health, 21 July 2014. Web. 23 September 2014.

[2] Zimmerman, M.A., and S. Warschausky. "Empowerment Theory For Rehabilitation Research: Conceptual And Methodological Issues." Rehabilitation Psychology 43.1 (1998): 3-16. Scopus®. Web. 18 April 2014.

[3] Colombo, R., Pisano, F., Mazzone, A., Delconte, C., Micera, S.,Carrozza, M., Dario, P., and Minuco, G. (2006). Design strategies to improve patient motivation during robot-aided rehabilitation. Journal of NeuroEngineering and Rehabilitation.

[4] B. English and A. Howard, "Engagement study of an integrated rehabilitation robotic tablet-based gaming system." *Advanced Robotics and its Social Impacts (ARSO), 2014 IEEE Workshop on* , vol., no., pp.14,19, 11-13 Sept. 2014