Increasing Motor Learning During Hand Rehabilitation Exercises Through the Use of Adaptive Games: A Pilot Study

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ABSTRACT

Physical therapy is a common treatment for the rehabilitation of hemiparesis, or the weakness of one side of the body [1]. Unfortunately, a recent study found that about one third of stroke patients who are prescribed rehabilitation in hospital settings are ranked as poor participators in physical therapy [2]. In an attempt to increase morale and participation of stroke survivors in hand function motor therapy, a robotic rehabilitation system is being designed to counteract these hindrances to hand function recovery. For this system, an adaptive game that is only controllable through hand movement has been designed to optimize the challenges and rewards presented to the user. A healthy subjects pilot study was conducted to assess the adaptive game's ability to increase the motor learning of participants during rehabilitation exercises. During this experiment, participants were asked to wear a robotic wrist sensor that functions as a game controller and play a rehabilitative tablet game that encourages therapeutic motions. To play this game users had to reach various targets in the game scenario by moving their hand in pre-determined ranges of motion. Two game scenarios presented the participant with a constant level of challenge, one of which was an easy scenario and the other a hard scenario, while a third scenario adjusted the game difficulty in order to maintain a constant balance of challenge and reward. When participants were presented with a constant level of challenge, their performance did not increase or decrease linearly during the session. This lack of linear growth or decay suggests that the participants did not experience significant learning and their performances were not hindered by negative emotions such as frustration or boredom. Participants that played the adaptive scenario performed similarly to the fixed difficulty levels when presented with an easy scenario for the beginning portion of the gaming experience and a difficult portion at the end. However, if participants were presented with a difficult scenario at the beginning of their gaming experience and an easy scenario at the end, they performed similarly to the fixed difficulty during the hard portion yet much better than the fixed difficulty during the easy portion. The averages for the easy portion of the adaptive level and the fixed easy level were 90.33% and 82.72%, respectively, and the standard deviations were 10.25% and 17.82%, respectively.

Author Keywords

Adaptive Games; Robotics; Human-Robot Interaction; Rehabilitation Robotics

ACM Classification Keywords

I.2.9 Robotics; I.2.1 Artificial Intelligence - Applications and Expert Systems

BACKGROUND

Physical therapy is a common treatment for the rehabilitation of hemiparesis, or the weakness of one side of the body. Stroke, which effects roughly 795,000 Americans per year, is a common cause of hemiparesis [1]. The limitations caused by reduced wrist and hand movements are a key factor associated with reduced perception of quality of life [3]. Through physical therapy exercises, patients can regain strength and improve their ability to use weakened body parts to perform daily activities. Unfortunately, physical therapy, in general, is a painful process that patients do not enjoy participating in. Furthermore, the attitude of the patient directly correlates to their compliance and success during physical therapy sessions [4]. Rehabilitation studies have shown that motivating and empowering patients by providing them with the perception of control can expedite the achievement of the patient's rehabilitation goals [5]. A recent study found that about one third of stroke patients in rehabilitation hospitals are 'poor participators' as ranked on the Pittsburgh Rehabilitation Participation Scale [2]. Thus, improvements upon outpatient stroke rehabilitation will benefit a large portion of our population.

In order to optimize learning of any skill, motor function included, the difficulty level of the task must be optimized

[6]. If a task is too easy, the learner is likely to progress slowly, become bored, or give up. If a task is too difficult and does not provide sufficient positive feedback, the learner might become frustrated and is also likely to give up. Optimizing the amount of difficulty and reward in hand function therapy could be used to increase engagement and morale as well as to promote patient participation and therefore learning during therapy sessions.

ROBOTIC REHABILITATION SYSTEM

A hand function rehabilitation gaming system has been created to facilitate supplementary therapy sessions. The goals of this system are to increase engagement and morale of its users. In its current form, this system, shown in Fig 1, includes an arm robot, a microcontroller, and a tablet. The participant completes wrist flexing exercises while wearing the arm robot, which functions as a wearable sensor. The value of the wrist angle is read from the robot by the microcontroller and transmitted, in real time, via Bluetooth to the tablet. On the tablet, an asteroid destroying game called RoboBlaster, shown in Fig 2, uses the wrist position, which is detected by the robot, to determine the position of the spaceship, which continuously fires lasers to destroy asteroids [7,8]. RoboBlaster provides challenge to the users by presenting targets, which encourage users to move. This game also rewards the users by providing them the satisfaction of destroying the asteroids as well as a game score.

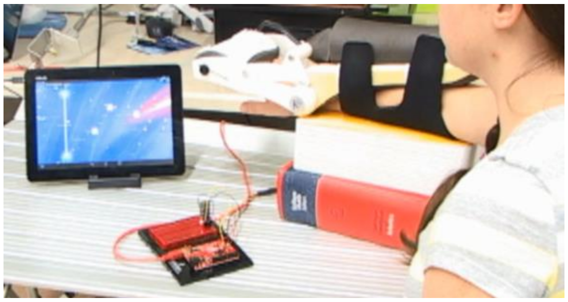

Figure 1. A participant using the rehabilitation system.

EXPERIMENTAL DESIGN

A healthy subjects test has been conducted. The inclusion criteria for this study is healthy adults. Ten participant have completed the study. For the experiment, participants were asked to play one RoboBlaster scenario using the robotic rehabilitation system as a game controller. Each game scenario presented asteroid targets to the participants using a random placement scheme to determine the y-position of the targets. Three difficulties were used as test cases. The duration of each scenario was 9 minutes and 36 seconds.

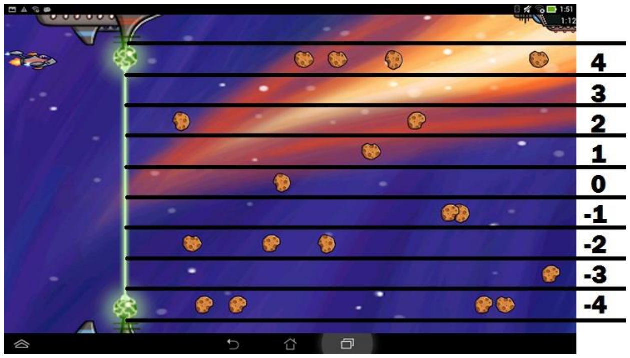

Figure 2. RoboBlaster tablet game, which is played by moving the spaceship (upper left) up and down by flexing the wrist. Lasers (not depicted here) are continuously fired from the spaceship and destroy the asteroids, which approach in the lanes from right.

Fixed-High-Frequency

The fixed-high-frequency level of the RoboBlaster uses a fixed, high frequency for launching targets. These targets launch once every 0.3 seconds. Fig 3, a screenshot of the fixed-high-frequency level, shows the amount of the targets on the screen at a given point in time. In order to successfully hit these targets, the spaceship must be constantly moving at an extremely fast pace. This scenario launches asteroids at the same speed that the spaceship shoots lasers. However, the spaceship cannot traverse more than a quarter of the screen in the 0.3 second time period between asteroid launches. So, if adjacent asteroids appear more than ¼ of the screen apart from one another, it is not possible for the participant to hit both of these asteroids. Thus, it is impossible for the participants to score perfectly in this scenario and is very difficult for them to score well.

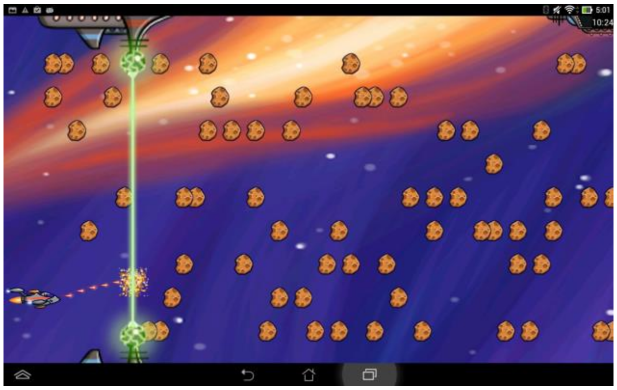

Figure 3. Fixed-high-frequency level of RoboBlaster.

This level was designed to provide constant challenge to the participants. We hypothesize that the difficulty of this level will frustrate the participants and cause them not to perform their best, due to their frustration in controlling their spacecraft with respect to the asteroids.

Fixed-Low-Frequency

The fixed-low-frequency level of the RoboBlaster uses a fixed, low frequency to launch targets. In this scenario, the targets launch once every three seconds. Fig 4, a screenshot of the fixed-low-frequency level, shows the amount of the targets on the screen. In this level, the participant may move the spaceship lethargically and still have high success with destroying asteroids.

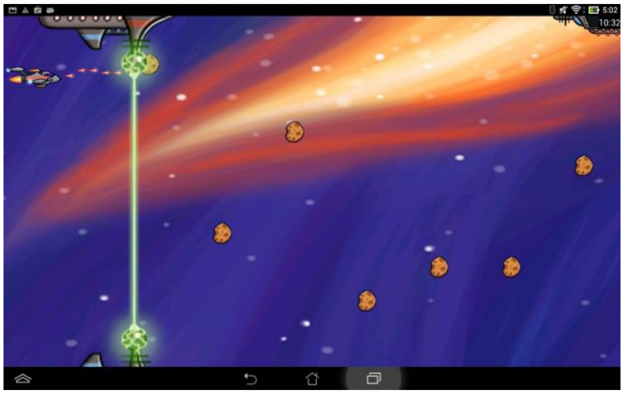

Figure 4. Fixed-low-frequency level of RoboBlaster.

This level was designed to be consistent, yet significantly easier than the fixed-high-frequency scenario. We hypothesize that the simplicity of this level will cause the participants to become bored and, as a result, their performance will decrease after a sufficient amount of time.

Adaptive

The adaptive level uses a feedback loop to maintain a fixed amount of success by varying the frequency at which the targets are launched. For this experiment, a running accuracy of 50% was maintained during the level. The running accuracy is calculated by dividing the number of targets that have been successfully destroyed by the total number of targets, destroyed or not, that have traversed the screen, once they have been removed from game play. The game initiated with a target launching frequency of one asteroid per second, shown in Fig 2. The running accuracy of a participant is calculated in real time during the game play, meaning that accuracy values are calculated using all data from the initiation of the level until the current time. When the participant deviates from the fixed running accuracy of 50% by more than 5%, the frequency at which the asteroids are launched begins to adjust. If the participant becomes more than 55% accurate, the game will launch the asteroids at a faster rate in order to increase the number of targets on the screen and thus the challenge of the task. If the participant becomes less than 45% accurate, the game launches asteroids at a slower rate in order to simplify the task by reducing the number of targets. In these scenarios, the speed at which the asteroids are launched will increase or decrease, respectively, by a factor of two every 2 seconds, until the participant's running accuracy returns to 50%. The highest frequency that the asteroids will be launched once each 0.3 seconds, as shown in Fig 3, and the lowest is once each 3 seconds, as shown in Fig 4.

RESULTS

The number of hit targets and missed targets was recorded in real time during game play. For data analysis, the accuracy was calculated across 18 second windows for the duration of the game. This accuracy was calculated by dividing the number of asteroids that were successfully destroyed during an 18 second period of time by the number of asteroids that were removed from game play, either from being destroyed or moving past the spaceship without being hit, during that same 18 second period. The 18 second window was selected because this is the amount of time that it takes a newly initiated asteroid to move across the entirety of the screen. Scatterplots were created of these 18 second accuracy calculations.

Fixed Frequency Levels

Fig 5 shows the scatterplots for the fixed frequency levels. The fixed-low frequency, or easy, scenario graphs, located in the left column of Fig 5, has an overall mean accuracy of 82.72% and a standard deviation of 17.82%. The data appears to alternate between abnormally high accuracy points and abnormally low points, in an almost sinusoidal pattern. Since the game launches asteroids in random locations, the distance that a participant must move to hit two adjacent asteroids varies randomly. Below average accuracy windows were associated with adjacent asteroids that were far apart from one another, while high accuracy windows were associated with adjacent asteroids that required little to no movement in order to hit all of the asteroids.

The right column of Fig 5 shows the scatterplots for the fixed-high frequency, or hard, scenario. Once again, the data appears to alternate between high and low points in a sinusoidal pattern for these participants. However, in this more difficulty scenario, the data is more tightly clustered than the easier, fixed-low frequency scenario. In the fixed-high frequency scenario, the peaks of the sinusoids were correlated to times when a large cluster or line of asteroids appeared in the data. The troughs of the sinusoids were correlated to asteroids with an even distribution of asteroids on the screen. In the fixed-high frequency game scenario, the average accuracy was 39.27% with a standard deviation of 5.14%.

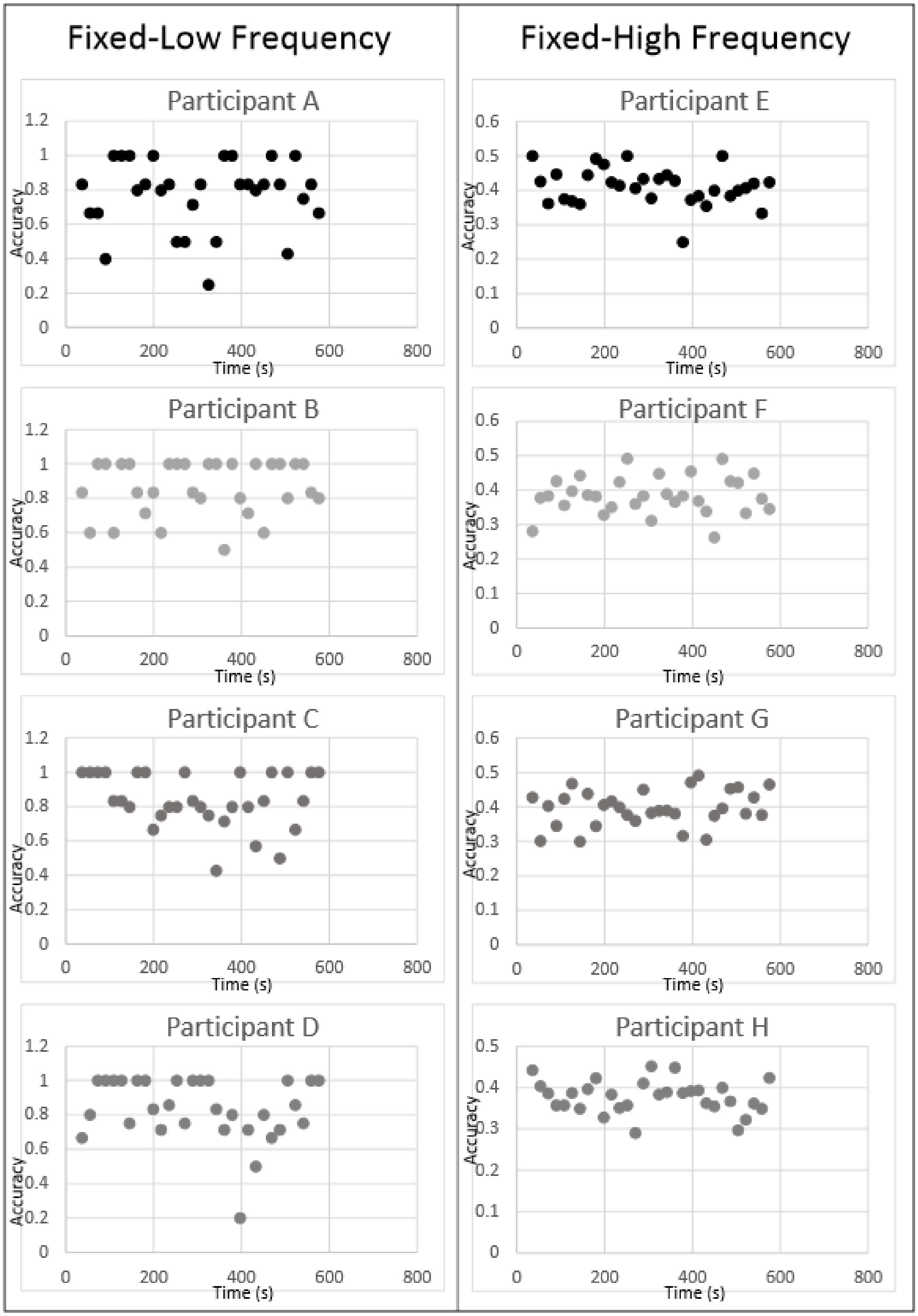

Figure 5. Scatterplots for the accuracies of the participants during fixed-low and fixed-high frequency RoboBlaster levels.

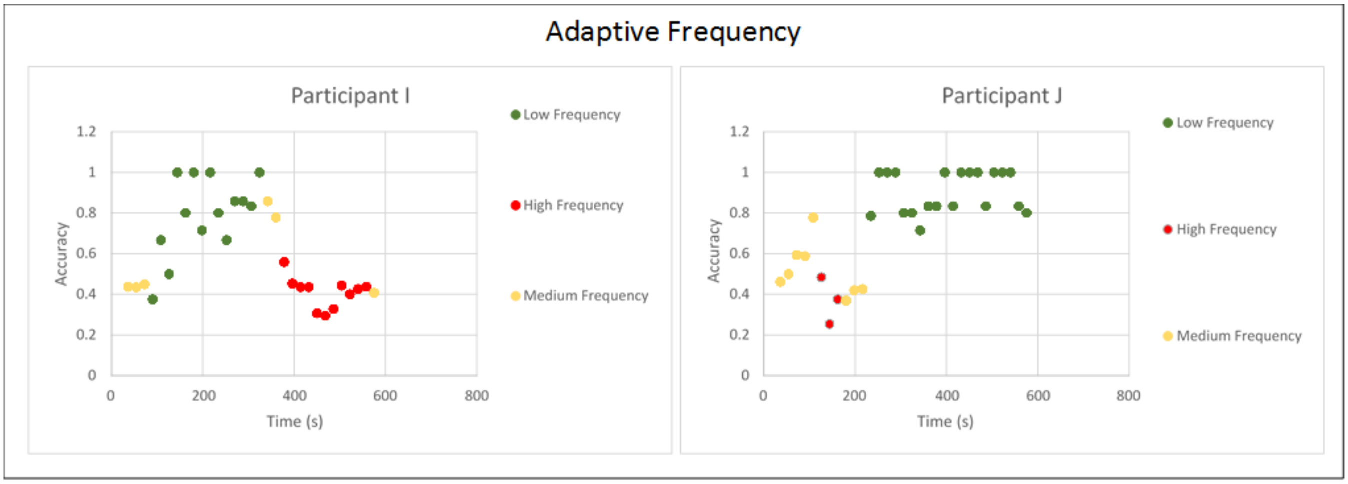

Figure 6. Scatterplots for the accuracies of the participants during adaptive RoboBlaster level.

Adaptive Level

Fig 6 shows the scatterplots for the two participants who played the adaptive scenario. The asteroid frequencies that participants were prompted with were recorded during game play. The 18 second windows in which participants were presented with an asteroid frequency of one asteroid every 3 seconds, the same frequency as the fixed-low frequency level, are marked in green; and the windows that presented participants with asteroids at a frequency of one asteroid every 0.3 seconds, the same frequency as the fixed-high frequency level, are marked in red. Time periods that the frequency was transitioning between these two extremes are marked in yellow.

Participant I was presented with the easiest, or lowest, frequency at the beginning of the game and the most difficult, or highest frequency, at the end of the scenario. The average accuracy and standard deviation for the easy portion of the scenario were 79.07% and 19.21%, respectively. The average accuracy and standard deviation for the difficulty portion were 41.06% and 7.64%, respectively.

Participant J was presented with the most difficult frequency at the beginning of the scenario and the easiest frequency at the end. The average accuracy and standard deviation for the initial difficult portion of the scenario were 37.04% and 9.38%, respectively. The average accuracy and standard deviation for the easy portion were 90.33% and 10.25%, respectively.

DISCUSSIONS

Fixed Frequency Levels

During the low and high fixed frequency levels, the participants' accuracy showed appears to have periods of time when the accuracies are abnormally high or low, in a sinusoidal pattern. These peaks and troughs in the data were a result of random placement of asteroid targets. During time periods with above average accuracy, the game was prompting the participants with an easier pattern of targets by placing asteroids nearer to one another. Below average accuracies were associated with difficult, dispersed asteroid patterns. Neither of these levels showed a significant linear increase or decrease in trend. This lack of linear growth or decay suggests that the participants did not experience significant learning and their performances were not hindered by negative emotions such as frustration or boredom. However, these sinusoidal performance trends that were associated with asteroid patterns show that the experiment had another difficulty parameter, the spacing of the asteroids. Participants performed better in sections of the game in which the random placement algorithm placed the asteroids in clusters. Participants did not perform as well when adjacent asteroids were far apart. This trend exposes that the difficulty was not truly consistent during these levels. Asteroid placement must be considered as a parameter in future experiments in order to create consistent difficulty in these fixed levels.

Adaptive Level

During the adaptive level, the frequency of asteroids that were launched changed according to the prior performance of the participant. Two participants completed this adaptive level. One participant experienced the easiest setting, the fixed-slow frequency, initially and was later prompted with the most difficult setting, the fixed-high frequency. The other participant experienced the most difficult setting early followed by the easiest setting later. The participant who experienced the easiest setting first performed similarly to the fixed difficulty levels for both the easiest and most difficult settings. The participant who experienced the most difficult setting first performed similarly to the fixed level for the most difficult setting. However, this participant showed a better performance for the low frequency portion of the level. Although this trend was not found to be statistically significant due to a small sample size, the trend suggests that learning is improved by providing motor learners a larger challenge at the beginning of their training followed by an easier version of the task.

CONCLUSIONS

This healthy pilot study suggests that robotic rehabilitation systems and adaptive games can be used to improve motor learning during rehabilitative exercises. If the benefits to learning that were seen in this study can be transferred to long-term rehabilitation setting, robotic rehabilitation systems with adaptive games could positively affect the motor function recovery of patients with a variety of motor function disorders.

FUTURE WORK

Experiments will be conducted to discover the best method for adapting the difficulty (i.e. adjusting asteroid size, frequency, speed, placement, etc.) as well as the adaptive algorithm that optimizes motor learning. In future experiments, the difficulty parameters will be isolated and more participants will be used in order to show that statistical significance. This experiment will also be repeated with elderly people and stroke survivors in a long-term study in order to verify the long-term effects of the robotic rehabilitation system on the rehabilitation process as well as to verify that the effects on engagement of the healthy subjects are consistent with those of the elderly and stroke survivor populations.

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