Encouraging Specific Intervention Motions via a Robotic System for Rehabilitation of Hand Function: A Healthy Pilot Study

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Abstract—A knowledge gap exists for how to improve hand rehabilitation after stroke using robotic rehabilitation methods, and non-robotic hand rehabilitation methods show only small patient improvements. A proposed solution for this knowledge gap is to integrate the strengths of three of the most favorable rehabilitation strategies for post-stroke rehabilitation of hand function, which are constraint-induced movement therapy (CIMT), high-intensity therapy, and repetitive task training, with a robotic rehabilitation gaming system. To create a system that is composed of collaborative therapy efforts, we must first understand how to encourage rehabilitation intervention motions. An experiment was conducted in which healthy participants were asked to complete six levels of a rehabilitation game, each level designed to encourage a specific therapeutic intervention, and a control, where participants were asked to complete undefined exercise motions. The results showed that participants' motions were significantly different than the control while playing each of the levels. Upon comparing the actual paths of participants to the paths encouraged by the levels, it was discovered that the participants followed the intended path while encouragement was being provided for them to do so. When the encouraged motions required quick, hard motions, the participants would follow an aliased version of the intended path. This study suggests that robotic rehabilitation systems can not only change how a participant moves, but also encourage specific motions designed to mimic therapeutic interventions.

I. Introduction

Stroke is the leading cause of long-term disability in America. A common disability that these patients suffer from is hemiparesis, or the weakness of one side of the body. Approximately 795,000 Americans suffered from a stroke last year, and about half of the survivors continued to suffer from hemiparesis six months after their strokes [1]. Patients suffering from hemiparesis may lose functionality in their wrists and hands. These limitations reduce patient independence and have been determined to be a key factor associated with reduced perception of quality of life [2]. Thus, developing methods of rehabilitating hemiparesis is of high importance.

Langhorn *etal.* [3] conducted a review of motor recovery therapies administered after stroke. This review shows that constraint-induced movement therapy (CIMT) is the most favorable method for rehabilitation of hand function. High-intensity therapy, which is an increased amount of therapy sessions, and repetitive task training, which is repeating specific motor sequences many times within a single training session, were also shown to be favorable methods for hand rehabilitation of stroke patients [3]. However, this review did not show robotic therapies to be favorable for hand recovery, even though it was one of the most favorable rehabilitation techniques for arm function rehabilitation [3]. Squeri *etal.* [4] completed a study in which chronic stroke patients participated in robotic sessions with an adaptive wrist rehabilitation robot that would encourage motions within the patients current range of motion (ROM). The robot would alter the assistance and range to accommodate the participants' current ROM. While use of this robotic system showed increases in patient ROM, this study did not compare its results to any control. Thus, it is unknown how this method compares to traditional therapy sessions. Kutner *etal.* [5] compared sixty hours of repetitive task practice (RTP) with thirty hours of RTP and thirty hours of Hand Mentor robotic-assisted therapy. The results of the Kutner *etal.* study showed no significant difference between the improvements of the two groups. Similarly, Hesse *etal.* [6] conducted a virtual reality experiment that used computer tasks to facilitate therapy. This experiment showed improvements in arm function, but not wrist or hand function.

Therefore, robotic rehabilitation for post-stroke hand function has not shown significant patient improvement and non-robotic rehabilitation for hand function only shows slight improvements. These trends suggest that there exists a knowledge gap in the implementation of effective robotic hand function rehabilitation for stroke patients. Furthermore, the review shows that all of these techniques (CIMT, high-intensity therapy, etc.) are only slightly more favorable than the control for hand function recovery, while they are largely more favorable than the control in recovery for other body parts [3]. Thus, a knowledge gap exists for how to improve hand rehabilitation after stroke using any technique.

A proposed solution for this knowledge gap is to integrate three of the most favorable rehabilitation strategies for hand function rehabilitation (repetitive tasks, CIMT, and high-

Fig. 1. The robotic system for rehabilitation of hand function, including a Hand Mentor (right), microcontroller and Bluetooth (middle), and tablet (left).

Fig. 2. A screen shot of the halfing algorithm level of RoboBlaster, the rehabilitation game, with lanes and lane numbers overlaid. The space ship (upper left) is controlled by the users' wrist motions. The asteroids initiate on the right portion of the screen and move horizontally to the left.

intensity) into a single robotic system. Such a collaboration of techniques would merge the strengths of each of these therapeutic techniques and could produce more favorable rehabilitation results. Hu $etal.$ [7] used a similar technique of combining rehabilitation methods to enhance rehabilitation outcomes. Hu $etal.$ combined an electromyography (EMG) driven electromechanical robotic system with neuromuscular electrical stimulation (NMES). In the associated experiment, the combination of NMES with robotic therapy was shown to result in more favorable wrist motion recovery than NMES or robotic interventions showed alone. Our proposed robotic wrist rehabilitation system would program repetitive tasks, similar to repetitive task training; only interact with the afflicted hand, like CIMT; and encourage increased amounts of therapy sessions, to mimic high-intensity therapy [3]. This healthy pilot study is a first step in configuring therapies by utilizing a robotic gaming system to encourage specific motions [8] that have been designed to mimic therapeutic interventions.

II. ROBOTIC SYSTEM FOR REHABILITATION OF HAND FUNCTION

The system discussed in this paper has been specifically designed for stroke patients who are undergoing rehabilitation therapy for hemiparesis of the wrist. The hardware of the system consists of a Hand Mentor (version 2005) [9], Asus mobile tablet, and additional circuitry [8]. As seen in Fig 1, these hardware components have been combined with a tablet gaming application to create an integrated rehabilitation gaming system. In this system, participants wear the arm robot and use their wrist motions to control tablet game characters. An accelerometer and microcontroller attached to the Hand Mentor robot are used to detect the wrist angle. A Bluetooth board is then used to forward the value to a tablet, which uses the wrist angle as an input to the rehabilitative game [8]. In this healthy pilot study, the arm robot did not assist participant motion.
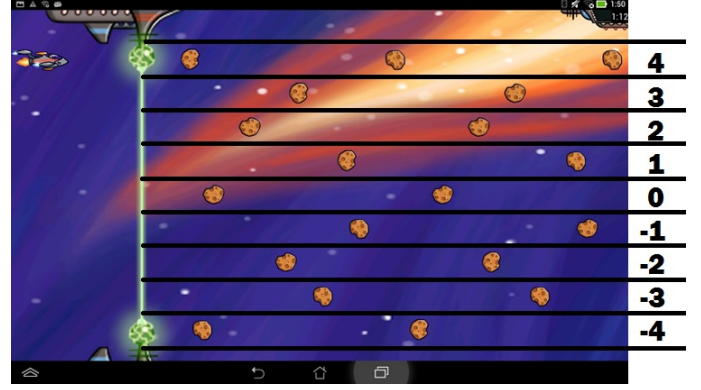
A. Rehabilitation Tablet Application

RoboBlaster, a tablet game shown in Fig 2, was selected as the rehabilitation game used in this study. In RoboBlaster, the user moves the space ship up and down, by moving their wrist inside the arm robot. During game play, the spaceship is continuously firing lasers (not depicted in Fig 2). The objective of the game is to shoot and destroy as many asteroids as possible to maximize the game score. Fig 2 shows that there are nine horizontal lanes, indexed -4 through 4, that can be occupied by the ship and asteroids.

B. Calculating Game Inputs

At the beginning of each session (prior to initiating game play), the microprocessor ran a subroutine that calibrated the central position of the wrist motions. During this subroutine, the participants were instructed to straighten their wrists. While the wrist was straightened, the subroutine would average the accelerometer readings for ten seconds. The resulting average was considered to be a wrist angle of $0°$. Then, the z-displacement was extracted, and the displacement angle was calculated, which was then transmitted via Bluetooth to the tablet. To calculate the displacement angle, the z-component of acceleration was measured. Since wrist motions are relatively slow and small compared to the effects of gravity, the readings of the accelerometer were dominated by gravitational forces. Therefore, the force values recorded by the accelerometer were considered to be directly proportional to position. Due to small angle approximations, it was assumed that the relationship between force and wrist angle was linear. Thus, a linear approximation was used to calculate the wrist angle from the z-force values. The approximation equation is shown in Eqn 1, where α denotes the angle and ΔF_z denotes the difference in z-force. The wrist angle range is between $-67.5°$ and $67.5°$, as these are the limits that the robotic arm can flex.

$$\alpha \propto 2/3 * \Delta F_z \qquad (1)$$

As the calculated angles are transmitted via Bluetooth to the tablet, the RoboBlaster game uses them to place the spaceship

TABLE I
MAPPING OF ANGLE RANGE TO LANE NUMBERS

Lane Number	Approximate Angle Range
-4	$-67.5\,^\circ \rightarrow -52.5\,^\circ$
-3	$-52.5\,^\circ \rightarrow -37.5\,^\circ$
-2	$-37.5\,^\circ \rightarrow -22.5\,^\circ$
-1	$-22.5\,^\circ \rightarrow -7.5\,^\circ$
0	$-7.5\,^\circ \rightarrow 7.5\,^\circ$
1	$7.5\,^\circ \rightarrow 22.5\,^\circ$
2	$22.5\,^\circ \rightarrow 37.5\,^\circ$
3	$37.5\,^\circ \rightarrow 52.5\,^\circ$
4	$52.5\,^\circ \rightarrow 67.5\,^\circ$

into the appropriate lane. Table I shows the scheme that RoboBlaster uses to map wrist angles to lanes within the game.

III. EXPERIMENTAL SETUP

Fifteen able-bodied participants between the ages of 14 and 35 completed this experiment. This protocol was approved by the Institutional Review Board (IRB) at Georgia Institute of Technology. The inclusion criteria for this study was healthy individuals. Eleven of the participants were male and four were female. All participants provided informed written consent. Each participant completed six levels of the game, as described in the following sections, each with a different asteroid placement algorithm to encourage a specific motion pattern. The participants also completed a control session, where they were instructed to exercise without the tablet game. The positions of their wrists were recorded during all of the sessions, including the control session. The participants completed the seven tasks (six levels and control) in a random order. The length of time that the participants spent in each task was one minute and twelve seconds. For each of the seven tasks, the percentage of time each participant spent in each wrist position and at each speed will be compared to the control using a t-test (without corrections). Actual paths and encouraged paths will be compared using correlation coefficients, which will be calculated using corrcoef, a normalized covariance MATLAB function.

A. Rehabilitation Asteroid Placement Algorithm

Six different levels of the RoboBlaster game were created, each with a different asteroid placement algorithm. These six algorithms are referred to as halfing, hold stretches, walking, random, up and down, and smaller range. These algorithms were designed to mimic wrist motor functions as tested by the Fugl-Meyer assessment, a movement examination that physicians routinely use to assess the recovery of stroke patients [10]. A seventh scenario was also run, a control.

1) Control: A control session was run for each of the participants. During this session, the participants were instructed to exercise while wearing the arm robot but without the tablet game for one minute and twelve seconds, the same duration of time as each of the game levels. Exercise motions were not defined for the participants. Thus, the path intended from this session was the naturally selected exercise path of each participant.
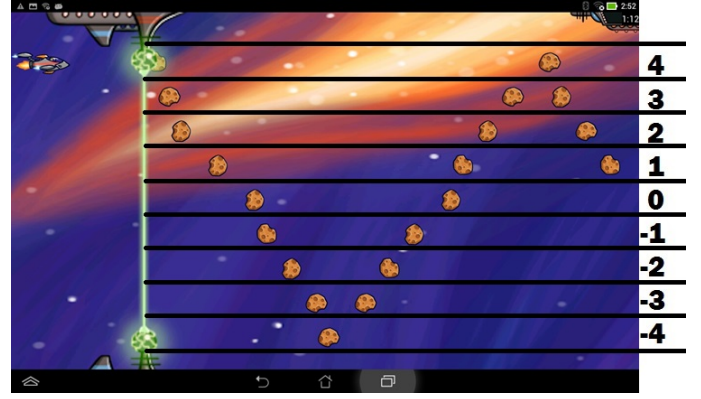

Fig. 3. Walking algorithm with lanes and lane numbers overlaid on the game.

2) Walking Algorithm: The walking algorithm repetitiously launches asteroids in the following sequence: 4, 3, 2, 1, 0, -1, -2, -3, -4, -3, -2, -1, 0, 1, 2, 3. This algorithm is designed to encourage a slower frequency oscillation with a large amplitude. It encourages slow and controlled wrist motions with equal time spent in lanes -3 through 3 and slightly less time spent in lanes -4 and 4. During the walking algorithm experimental sessions, each participant was presented with encouragement for five downward and four upward motions. In the Fugl-Meyer test, patients are required to perform smooth motions that alternate between maximum dorsiflexion and maximum volar flexion [10]. The walking algorithm, shown in Fig 3, was designed to encourage this smooth, alternating motion.

3) Halfing Algorithm: As seen in Fig 2, the halfing algorithm repetitiously launches asteroids in the following lane sequence: 4, -4, 0, 2, -2, 3, -3, 1, -1. This algorithm has been designed to encourage oscillation that vary in difficulty. First, the patient must reach to the maximum dorsiflexions and volar flexions. Then, the participant creates an oscillation that has an amplitude of half of their maximum range. Next, the required oscillation is 75% of their full range. Finally, the participant must complete an oscillation that is 25% of the full range. The participant repeats this oscillation pattern for the entirety of the gaming session. During the halfing algorithm experimental sessions, each participant was presented with encouragement for nine oscillations from the minimum to the maximum of their range, eight oscillations of 75% of their range, eight oscillations of 50% of their range, and eight oscillations of 25% of their range. This algorithm was designed to encourage the portion of the Fugl-Meyer test that requires alternating motions between maximum dorsiflexion and maximum volar flexion [10]. However, the variation of the levels of difficulty is designed to encourage growth and allow for partial success for participants who have not yet achieved high flexion in either direction.

4) Hold Stretches Algorithm: The hold stretches algorithm alternates launching 15 asteroids in lanes 4 and -4. This algorithm is designed to have the participants reach to their maximum dorsiflexion position and hold the stretch. Then,
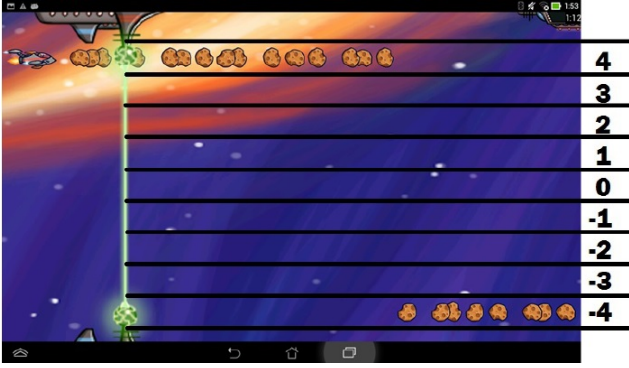
Fig. 4. Hold Stretches algorithm with lanes and lane numbers overlaid.

the participant must reach to their maximum volar flexion and hold the stretch. This process repeats. During the hold stretches algorithm experimental sessions, each participant was presented with encouragement for holding three stretches in their maximum dorsiflexion and three stretches in their maximum volar flexion. In the Fugl-Meyer test, wrist stability is tested. For this test, the wrist is held at approximately $15°$ dorsiflexion while a slight amount of resistance is added [10]. The hold stretches algorithm, shown in Fig 4, was designed to allow for practice of the wrist stability portion of the Fugl-Meyer test. This algorithm encourages a much higher maximum, of greater than $52.5°$. Since this system currently does not allow for resistance to be applied, a larger angle is used, to utilize naturally occurring resistance from tendons stretched to their maximum potential. The increase of the encouraged angle could be changed to fit the maximum range of each participant.

5) Random Algorithm: The random algorithm launches asteroids randomly in lanes -4 through 4. This algorithm was designed simply to encourage motion, without care as to the specific types of motions. It has been shown that patients who practice motions that are similar to various tasks are more capable of preforming said tasks [11]. The random algorithm was designed to allow for practice of a vast array of wrist motions and therefore practice the array of motions that are used in everyday life.

6) Up and Down Algorithm: The up and down algorithm alternates launching an asteroid in lanes 2, 3, or 4, with an asteroid in lanes -2, -3, or -4. The specific value within these two sets of lanes is randomly selected for each asteroid launch. The up and down algorithm is designed to encourage oscillations that have a high frequency and large amplitude. It randomly varies the difficulty of the oscillations. This algorithm is also designed to encourage wrist motion to maintain positions in the outer limits of the wrist range, while discouraging the participant from spending large amounts of time in positions that are in the center of the participant's ROM. During the up and down algorithm experimental sessions, each participant was presented with encouragement for 37 oscillations of varying difficulty. Like the halfing algorithm, this algorithm was designed to practice the alternating motion portion of

the Fugl-Meyer test with random levels of difficulty for each iteration [10].

7) Smaller Range Algorithm: The smaller range algorithm randomly launches asteroids in lanes -1, 0, 1, and 2. This algorithm is designed to encourage oscillations with small amplitudes and to encourage wrist positions in the center of the wrist movement range. It is designed to have a low level of difficulty for patients with smaller ROMs than normal.

IV. RESULTS

A. Positions and Speeds

During each of the game playing sessions, the wrist angle of the participant was recorded once a second. The percentage of game time spent in each position, as seen in Fig 5, as well as the percentage of time spent at each speed, as seen in Fig 6, were calculated. The speed of motions was calculated by finding the difference between the lanes for consecutive time samples. This speed is measured in degrees per second. Since each lane represents a $15°$ wrist arc, recorded speed values have 15 °/sec increments between them. The statistical significance of these values was calculated by using t-tests (without corrections) for each of the comparisons.

1) Control: When the participants where exercising without a tablet gaming stimulus, they tended to spend the most amount of exercise time at the maximum and minimum points of their ROMs, angles in the ranges $-67.5°$ to $-52.5°$ and $52.5°$ to $67.5°$. The speed at which they changed wrist position was evenly distributed between fast and short motions.

2) Walking Algorithm: The walking algorithm should encourage an even distribution of time spent at angles within the range of $-52.5°$ to $52.5°$ with less time spent at angles in the ranges $-67.5°$ to $-52.5°$ and $52.5°$ to $67.5°$. The algorithm should also encourage movements of one lane between each sampling point, or a change of $15°$ per second. The actual distribution of time spent in each lane is similar to the expected amount of time spent in each lane. A change of $15°$ per second is favored over all other changes; however, holding the angle constant is also a common amount of change. The amount of time spent at each of the angle ranges, except angles in the range of $-52.5°$ to $-37.5°$, were significantly different from the control, with p-values less than 0.01 for each of these lanes. The movement differences were also significantly different from the control for all movement speeds, except for changes of $45°$ per second. All other movement speeds had p-values less than 0.05. Since all but one of the angle ranges were found to be significantly different from the control, it can be deduced that the distribution of time spent at each angle is significantly different from the control. Since all speeds but one were found to be significantly different from the control, the distribution of speeds can also be considered to be significantly different from the control.

3) Halfing Algorithm: The halfing algorithm produced a fairly even distribution of time spent in each of the positions. While the algorithm was designed to encourage speeds of $30°$/sec, $60°$/sec, $75°$/sec, $90°$/sec, or $120°$/sec, actual speeds were shown to favor slower speeds. The highest concentrations
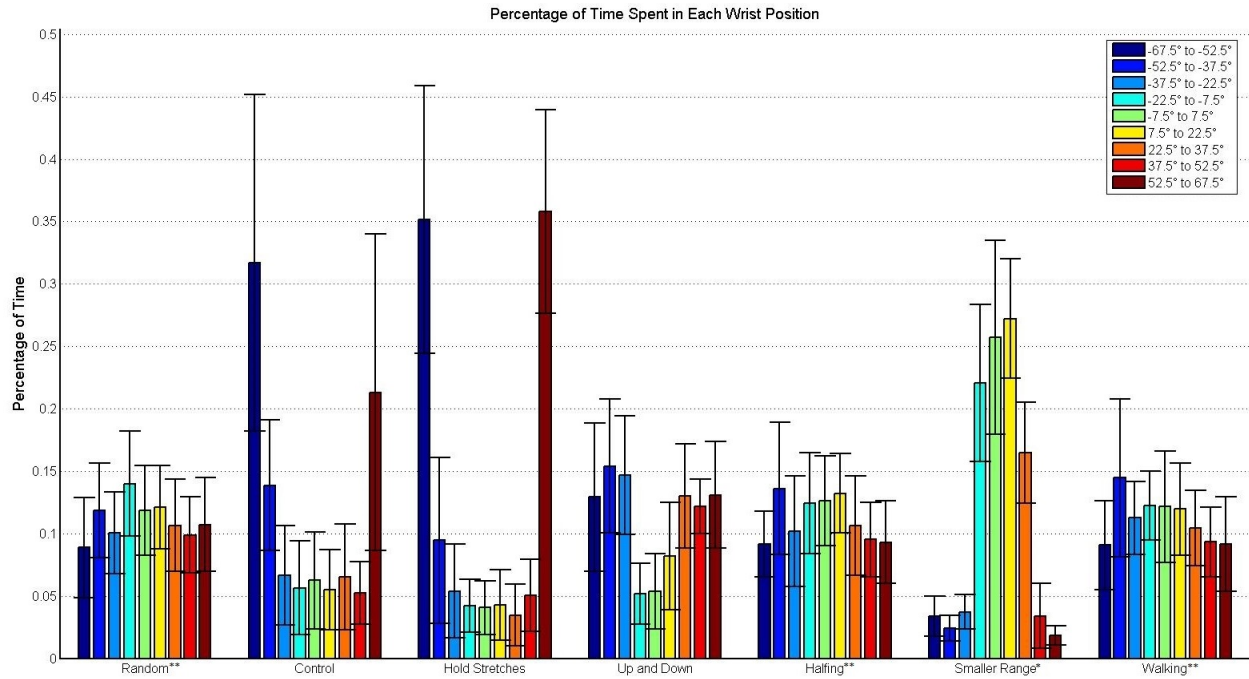
Fig. 5. Percentage of time spent in each wrist position during each of the scenarios. A single asterisk indicates that the percentage of time spent in each wrist angle range was significantly different from the control with p < 0.01 for all angle ranges. Double asterisks indicate that the percentage of time spent in each wrist position was significantly different from the control with p < 0.01 for all angle ranges, except for one range.
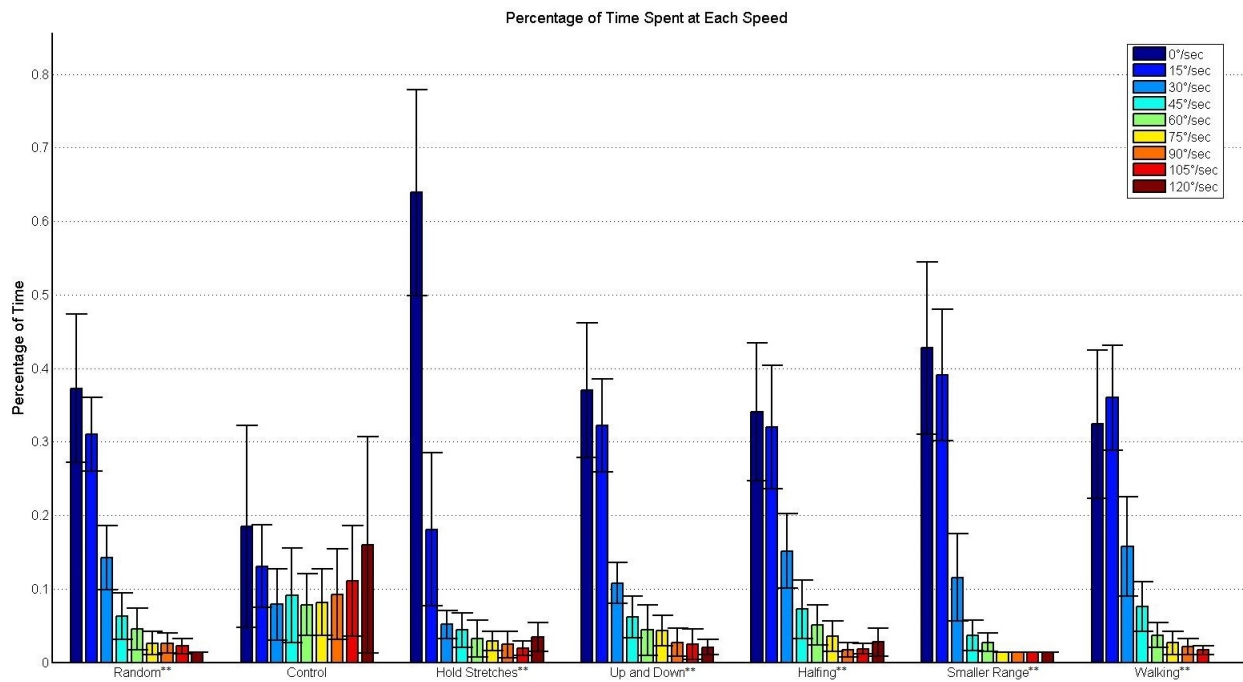

Fig. 6. Percentage of time spent at each speed during each of the scenarios. A single asterisk indicates that the percentage of time spent at each speed was significantly different from the control with p < 0.05 for all speeds. Double asterisks indicate that the percentage of time spent at each speed was significantly different from the control with p < 0.05 for all speeds, except for one speeds.

of speeds were of $0\,°$/sec, $15\,°$/sec, or $30\,°$/sec, respectively. The amount of time that the participants spent in each angle range was found to be statistically different from the control with p-values less than 0.01 for all ranges except $-37.5\,°$ to $-22.5\,°$. The percentage of time that the participants spent traveling at each speed, except for a speed of $45\,°$/sec, was found to be significantly different from the control with p-values less than 0.05. Therefore, the distribution of speeds and positions can also be considered to be significantly different from the control.

4) Hold Stretches Algorithm: The hold stretches algorithm attempted to encourage the participants to spend half of their game time in the wrist angle range of $-67.5\,°$ to $-52.5\,°$ and half of their game time in the wrist angle range of $52.5\,°$ to $67.5\,°$. If the participants followed the intended path, they would have had a speed of $0\,°$/sec for the majority of the game and a few $120\,°$/sec changes. The actual data showed that the participants did spend the majority of their time at angle ranges of $-67.5\,°$ to $-52.5\,°$ and $52.5\,°$ to $67.5\,°$. They had a majority of motion differences of $0\,°$/sec. However, their paths were smoothed slightly, and the participants spent a small portion of their time at angles between $-52.5\,°$/sec and $52.5\,°$/sec, and they had some speeds that were not $0\,°$/sec or $120\,°$/sec. The amount of time that the participants spent in each of the lanes was found to be significantly different from the control for position ranges of $7.5\,°$ to $37.5\,°$ and $52.5\,°$ to $67.5\,°$ using p-values less than 0.05. However, the amount of time that the participants spent within the angle ranges of $-67.5\,°$ to $7.5\,°$ and $37.5\,°$ to $52.5\,°$ were not found to be statistically different from the control. The difference between speeds of the participants' motions and the control motions was statistically significant for all speeds with a p-value less than 0.05, except for the speed of $15\,°$ per second. Thus, the distribution of speeds can also be considered to be significantly different from the control. These discrepancies suggest that participants were naturally inclined to smooth motions.

5) Random Algorithm: The random algorithm has a fairly even distribution of game time throughout the positions. Actual position changes were shown to favor more slight differences, with the highest concentrations of speed of $0\,°$/sec to $15\,°$/sec. The amount of time spent in each position range during this gaming session was found to be statistically different from the control with p-values less than 0.01 for all ranges except $-52.5\,°$ to $-37.5\,°$. The speed of motions was found to be significantly different from the control for all speeds except for $45\,°$/sec. The statistically different speeds had p-values less than 0.01. Thus, the distribution of positions and speeds can also be considered to be significantly different from the control.

6) Up and Down Algorithm: The up and down algorithm should have encouraged participants to have large wrist angle changes between sampled positions as well as to spend the majority of their time in the outer ranges, $-67.5\,°$ to $-22.5\,°$ and $22.5\,°$ to $67.5\,°$. The algorithm aimed to encourage less time spent between the angles $-22.5\,°$ to $22.5\,°$. While participants did spend more time in the outer ranges, some time was spent

in the inside ranges. Also, the trend shows that the participants once again favored slight movements despite our attempt to encourage large difference motions. This algorithm showed a statistically significant difference for the amount of game time spent in wrist angle ranges $-67.5\,°$ to $-52.5\,°$, $-37.5\,°$ to $-22.5\,°$, $22.5\,°$ to $37.5\,°$, and $37.5\,°$ to $52.5\,°$, as compared to the control, with p-values less than 0.0001. However, the amount of time spent in the wrist angle ranges $-52.5\,°$ to $-37.5\,°$, $-22.5\,°$ to $22.5\,°$, and $52.5\,°$ to $67.5\,°$ were not found to be significantly different from the control. The difference between the speed of movements that the participants made each second as compared to the control was found to be statistically significant for all speeds, except for a difference of $45\,°$/sec. These differences had p-values of less than 0.05. Thus, the distribution of speeds can also be considered to be significantly different from the control. The discrepancies from the intended path once again suggest that the participants' motions represent a smoothed version of the algorithm.

7) Smaller Range Algorithm: The smaller range should have encouraged participants to make small changes between sampled positions as well as to spend the majority of their time in the wrist position range of $-22.5\,°$ to $37.5\,°$. The results suggest that this type of movement was successfully encouraged. The participants spent significantly more time in the desired wrist position range of $-22.5\,°$ to $37.5\,°$ as compared to the outer ranges of $-67.5\,°$ to $-22.5\,°$ and $37.5\,°$ to $67.5\,°$. Also, small changes in motion were seen for this experiment. Speeds between $0\,°$/sec and $15\,°$/sec were seen more frequently than larger motions. The amount of game time spent in each wrist position was significantly different from the control, with p-values less than 0.005. The speed of the motions was found to be statistically different from the control with p-values less than 0.001 for all speeds, except for a speed of $30\,°$/sec. Therefore, the distribution of speeds and positions can also be considered to be significantly different from the control.

B. Path Approximations

The differences between participants' actual paths and the intended paths were graphed for the walking and hold stretches algorithms, shown in Figs 7 and 8, respectively. A trend that is learned from these comparisons is that the participants aligned most accurately with the encouraged path during the beginning of the game. The correlation coefficients between the intended paths and the median actual paths for the walking and hold stretches algorithms were found to be 0.44 and 0.75, respectively. At the beginning of each session, the actual path aligns more closely with the encouraged path and the standard deviations between the participants' movements tend to be smaller. As time progresses, the average real path of the participants becomes more erratic and the standard deviation becomes larger.

C. Aliasing

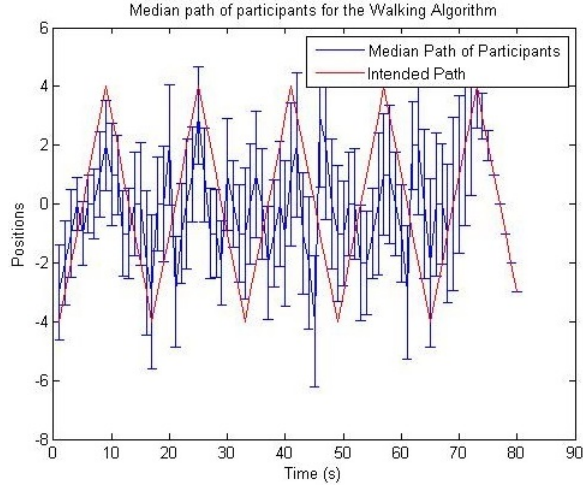Algorithms that involve frequent, rapid changes between asteroid locations did not encourage frequent, rapid movements

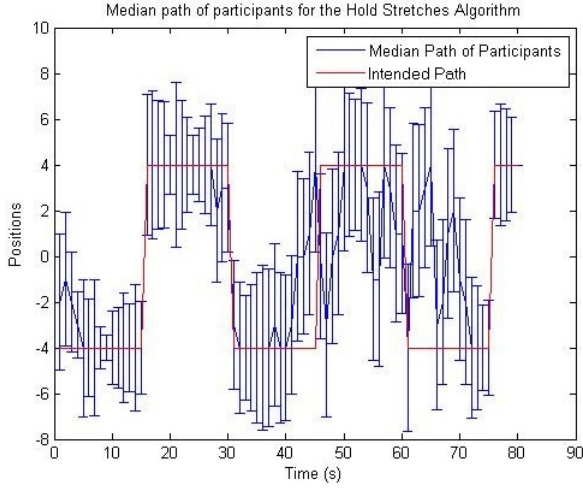Fig. 7. Difference from intended path for the walking algorithm.

Fig. 9. The halfing algorithm plotted with the intended path.

Fig. 8. Difference from intended path for the hold stretches algorithm.
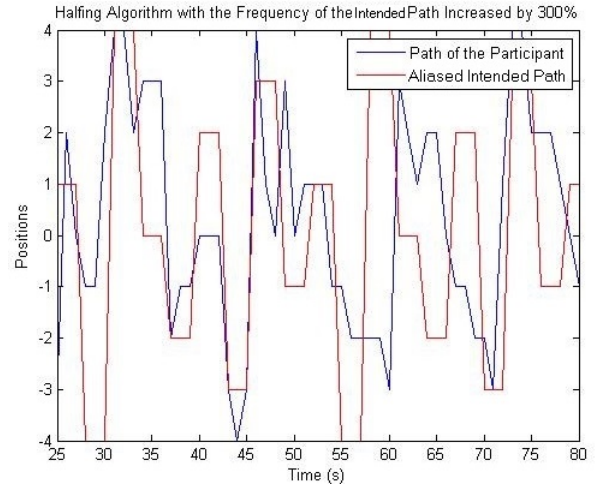
Fig. 10. The halfing algorithm plotted with a 300% frequency increase of the intended path.

from the participants. However, an aliasing of the intended path occurred, as it does in an under-sampled signal. The path that the participants followed better fits a path of the algorithm with a lower frequency. Each participant followed a signal with a different frequency. For example, one of the participants followed a signal that was best fit by a 300% increase of the intended path. Fig 9 shows the participant's path plotted with the non-aliased version of the intended signal, while Fig 10 shows the participant's path plotted with an aliased signal with a frequency of 300% of the intended frequency. The correlation coefficients for the non-aliased and aliased paths were found to be 0.14 and 0.41, respectively. From these figures, it can be seen that, the aliased version is a better fit than the non-aliased version.

V. DISCUSSION

The results of this healthy pilot study suggest that not only can robotic rehabilitation systems change how a participant moves,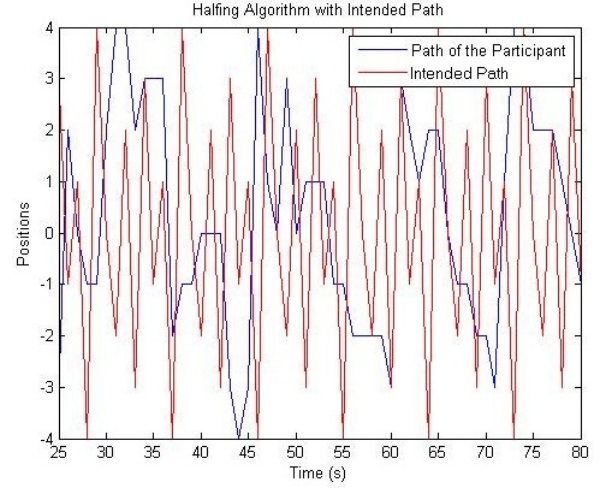 but can also encourage specific motions designed to mimic therapeutic interventions. This study also exposed two important considerations, frequency of targets and game speed, that need to be taken into account in order to encourage participants to follow the encouraged path precisely.

A. Path Approximations

During data analysis, it was discovered that participants followed the encouraged paths closely at the beginning of each of their sessions. However, as time progressed, their paths became less predictable and the standard deviations between these paths became larger. This trend occurs because of an error in game design. The lasers that are fired by the ship move slowly. Lasers are also fired at a faster rate than asteroids are launched. As a result, residual lasers from a previous target will remain on the screen after the target asteroid has been destroyed. As the game progresses, these residual lasers will begin to destroy asteroids as they appear, removing the encouragement for the participants to move to the wrist

position that corresponds to the asteroid's lane placement. The effects of this become prevalent at roughly 40 seconds into the session. The correlation coefficients between the intended paths and the median actual paths for the first 40 seconds of the walking and hold stretches algorithms were found to be 0.50 and 0.98, respectively.

B. Aliasing

It was also discovered that an aliasing effect occurs between the actual path participants followed and the encouraged path when the encouraged path presented frequent, rapid changes between targets. This suggests that participants prefer slow, smooth paths to quick, harsh motions. In levels with rapid fluctations of targets, each of the participants exhibited this trend with a different frequency of the intended path. This suggests that each individual has a maximum preferred speed at which they feel most comfortable moving. This maximum preferred speed appears to be a different speed for each individual. When the encouraged path's speed exceeded the participants' maximum preferred speed, the participants would alias the encouraged path to their maximum preferred speed.

VI. CONCLUSIONS

This healthy pilot study shows that robotic rehabilitation systems can not only change how a participant moves, but also encourage specific paths. The motivation of this project is to use the system to facilitate therapy sessions for stroke patients in a robotic and gaming environment. Showing that our system is capable of encouraging motions that mimic therapeutic interventions was a preliminary task for producing a novel robotic wrist rehabilitation system that integrates the strengths of three of the most favorable rehabilitation strategies for post-stroke rehabilitation of hand function.

VII. FUTURE WORK

This study exposed some important variables for more precisely encouraging paths. One must avoid participant aliasing of the encouraged path by encouraging motions that move at a similar speed to which the participant is comfortable moving.

Currently, the game contains a design construct that results in slow moving lasers, which are fired from the ship to destroy the asteroids. Lasers are also fired at a faster rate than asteroids are launched. As a result, residual lasers from a previous target will remain on the screen after the target asteroid has been destroyed. This error allows for the residual lasers to destroy asteroid targets as they appear, and thus removes encouragement for the participants to follow the intended path. To rectify this issue and strengthen the encouragement factor for the intended path, the software will be optimized to reduce the amount of lasers that are on the screen at any given point in time.

It was also discovered that participants had a unique maximum preferred movement speed that was different for each participant. If the game encouraged movements faster than the participant's preferred movement speed, the participant would follow an aliased version of the path. To correct this problem, the paths of the asteroids and the game speed will also be modified to reduce the aliasing effect. Once these parameters are optimized, the study will be continued to verify our ability to encourage specific paths. To accommodate users with different maximum preferred movement speeds, the speed of the game will become a variable that can be selected by the user as a difficulty level.

In order to increase accuracy of patient motions and remove the need for wrist position calibration at the beginning of each session, future versions of the arm robot will utilize a potentiometer to calculate wrist angle, instead of the currently implemented accelerometer. Future experiments will also record data at a higher sampling rate to provide additional precision of results.

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