Development of the Home Arm Movement Stroke Training Environment for Rehabilitation (HAMSTER) and Evaluation by Clinicians

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Abstract. Stroke commonly results in severe impairment of upper extremity function, which limits independence in activities of daily living. Continued and frequent use of the affected limb can result in increased function. However, long term access to therapy is frequently limited, and home exercise compliance is low. The following paper presents the design and clinician evaluation of a Kinect based home therapy system called Home Arm Movement Stroke Training Environment (HAMSTER). The development, which focused on reducing commonly observed impairments after stroke, is discussed. Additionally the system was evaluated by twelve clinicians (occupational and physical therapists) with an average of 18 years of clinical experience with individuals with chronic stroke. The clinicians were asked about commonly prescribed home exercises, and for feedback about the HAMSTER system. Although only two of the clinicians had used the Kinect previously, the clinicians reported good usability and general satisfaction with the system. All of the clinicians felt that HAMSTER would be beneficial for individuals with chronic stroke.

1 Introduction

Stroke is the leading cause of long lasting adult disability [1]. Upper extremity function is commonly impaired after stroke and negatively affects quality of life. Therapy and intense use of the affected arm is effective for improving function [2]. However, transportation and cost are significant barriers to physical activity after stroke [3]. Nonuse leads to muscle deconditioning, which furthers the effects of stroke related impairment. In a US national survey of 312 individuals with chronic stroke only 31% reported that they exercise regularly and 27% reported rare or no exercise [4]. 86% of these individuals reported that they would be interested in an exercise program if one were available to them. However, compliance with home exercise programs is frequently low. In another study, lack of motivation was the largest reported reason for noncompliance with home exercise by individuals with chronic stroke related disability [5].

Home rehabilitation programs offer increased therapy hours at a potentially reduced cost and increased convenience to individuals with chronic stroke [6].

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Game based systems are motivational and provide users with a sense of accomplishment that encourages continued use. A small study showed that the use of games increased therapy compliance in individuals with cerebral palsy that had previously abandoned therapy [7]. Additionally, computer games can offer accountability by recording system usage and potentially providing this data to clinicians. Several virtual reality systems have been used for therapy for individuals with stroke related disability. These systems typically involved wearable [8] or handheld sensors like the Wii [9]. Wii therapy studies have shown an increase in physical activity with a potentially more motivational intervention then general exercise [10]. However, wearable and handheld sensors can be difficult for individuals with commonly occurring hand impairments to hold or don independently. Additionally, these systems allow compensation strategies, such as flicking the wrist instead of swinging the whole arm in the Wii bowling game. These compensation methods will likely limit the functional recovery from the intervention [11] [12]. Furthermore, many systems use commercially available games, which do not sufficiently address the impairments of the user [10]. Stroke can result hemiparesis, spasticity, loss of normal joint coordination, and abnormal muscle synergies in the affected arm [13]. These conditions require thoughtful consideration during system design for this population. Conventional games may encourage abnormal or undesirable movement patterns in individuals with stroke. It is vital that the therapy be appropriately directed toward the user's unique impairments, encourage use of the affected arm without frustration, and avoid compensation strategies, which have been shown to limit recovery [11] [12].

The recent development of the Microsoft Kinect has opened up the field of virtual reality for rehabilitation. The Kinect is a low cost, $100, vision based sensor that is used for skeleton tracking in gaming environments. The Kinect does not require sensors to be placed on the user, which allows for quick and easy setup. While the Kinect currently cannot obtain research grade motion tracking accuracy, the low cost and minimal setup time make the Kinect preferable in many situations. There have been a few relevant studies looking into the use of the Kinect for rehabilitation. One group examined the use of three commercially available Kinect games for children with degenerative ataxia and observed significant reductions in ataxia symptoms and improvements in balance [14]. Researchers have shown increased client motivation to do rehabilitation exercises with the Kinect and increased correctness of movement during training exercises [15].

The following paper presents the development of the Home Arm Movement Stroke Training Environment for Rehabilitation (HAMSTER) system for home use by individuals with chronic stroke. The system design focused on providing clinically relevant tasks with good general usability. This increases the likelihood that the system will improve function in individuals with stroke and potentially increase exercise compliance. Additionally, the system evaluation by clinicians discussed in this paper supports the potential success of the system.

2 System Development

Four sample therapeutic games were created for the Kinect. The games were designed using the Windows SDK v1.5, Microsoft XNA, and Farseer Physics Engine. All of the games were developed for use in the seated posture, due to potential safety concerns when the system is implemented in the home. The seated mode in the Windows SDK was not utilized since this would remove feedback about the subject's trunk motion. Instead standing mode was used and tracking of the lower limbs, which are difficult to distinguish from the chair, was simply ignored.

Simple graphics were developed for each game to minimize distraction and possible confusion. The visual interface for each of the games is shown in Figure 1 along with an image of a clinician user. The targeted arm movement varies widely between tasks to encompass a variety of potential exercises.

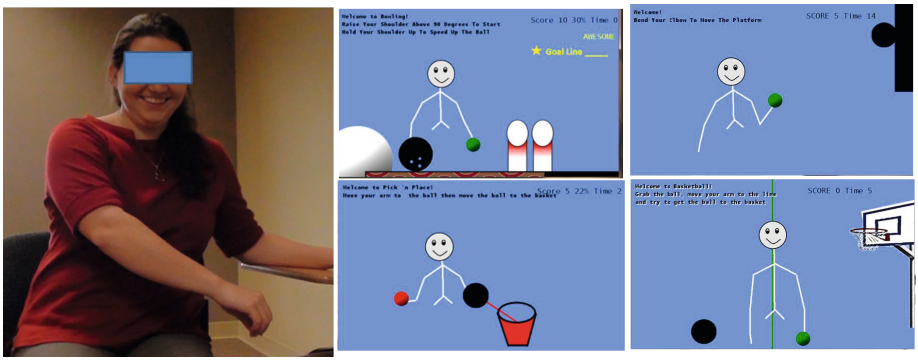

Fig. 1. On left a clinician plays the Pick and Place game. The Pick and Place graphics are shown in the lower adjacent image. The Bowling is shown above Pick and Place. The third column is Ping Pong, on top, and BasketBall below.

2.1 Bowling

The movement pattern of isolated shoulder movement with elbow extension was identified for the first task. The process of shoulder flexion with a straight elbow is often difficult after stroke due to the commonly occurring abnormal flexor synergy, which results in elbow flexion with shoulder movement. This game may help individuals break out of the abnormal flexor synergy pattern and potentially improve functional reach. In the Bowling game, the user is asked to hold their arm up to a certain height with their elbow extended. When the user achieves the goal position an impulse is applied to a bowling ball. The user receives points when the bowling ball knocks down the pins. Since elbow flexion is commonly elicited unintentionally after stroke, the game focuses on maintaining elbow extension

with shoulder flexion. An error message appears and the ball will slow if the user's shoulder is above the goal line but their elbow is too bent or if the user's shoulder is horizontally abducted. If the ball has not started moving, no movement will be initiated with the elbow bent or shoulder horizontally abducted. If the user scores more than 6 points within 12 seconds the game automatically increases the difficulty by increasing the required shoulder flexion angle.

2.2 Pick and Place

The second task builds off the skills of Bowling for coordinated elbow and shoulder movement while crossing midline. This movement is more analogous to functional reach. During the Pick and Place game, the user is asked to retrieve the ball and move it into the basket. After a point is scored the ball reappears in a new target position with a different horizontal position on the screen. As the game progresses the user will have to also raise their arm to grab the balls, thus increasing the difficulty of the game. This change in difficulty is done between training sessions based on the previous session's score. The system displays an error message and does not allow for task completion if the user tries to use the unaffected hand to assist with the movement.

2.3 Ping Pong

The clinical focus of Ping Pong is isolated movement of the elbow. Control of the elbow is often limited after stroke due to spasticity. The velocity dependent aspect of this game could help increase the control of the joint at different speeds. Range of motion can also be increased as the subject progresses. It is recognized that the velocity dependent nature of this task may result in increased spasticity and that a delicate balance of speed and range of motion will need to be reached for each individual. During the Ping Pong game the user is asked to flex and extend their elbow to move a paddle to hit a ball that is moving across the screen. The ball gets progressively faster with successful hits and slows down when the ball is missed. The user gets a point for each successful ball hit.

2.4 Basketball

The clinical focus of this game is coordinated movement of the shoulder and elbow with an additional cognitive aspect of determining where the user needs to release the ball. To complete the task the individual will use a modified proprioceptive neuromuscular facilitation (PNF) movement pattern, which encourages maximal muscle activation. During the Basketball game the user is asked to retrieve the ball from across their body and then move it over the line in a position that will make the ball hit the basket. After the user successfully completes the task four times, the trajectory line changes to require more shoulder flexion.

3 System Testing with Clinicians

The protocol was approved by the University of Pittsburgh Institutional Review Board. Twelve clinicians were recruited for initial testing of the HAMSTER system via focused interviews. All subjects provided informed consent. During testing the users were always in sitting position at a distance of approximately four feet from the Kinect and computer. The screen was a 13 inch screen of a laptop. This was chosen for portability since, for the clinician's convenience, testing frequently occurred at the clinician's workplace.

Initially the clinicians completed a form asking general demographic information including number of years in clinical practice, type of home exercises usually prescribed, and perceived level of client compliance with the exercises. The procedure for each game was described prior to testing using a script guideline. The researcher's clinical goal for the game was not described. Clinicians played each game for two minutes. After one minute of the Pick and Place game, the difficulty level was increased as would be done automatically between therapy sessions. The user then played the game for an additional minute with targets requiring more shoulder flexion.

After each two minute game trial the subject was given time to jot down notes and give a general usability score from 1-4 where 1 was poor and 4 was excellent. Video recording was also used and clinicians were informed that they could also provide feedback orally. Following completion of the study, the clinician filled out a questionnaire. In the questionnaire the clinicians were asked about various aspects of the system, which covered usability, graphics, and how well HAMSTER would fulfill its role as a home therapy system.

4 Results

On average, the twelve recruited clinicians were 44 years old with a standard deviation of 15 years. The clinicians had an average of 18.8 years, with a standard deviation of 14.1 years, of clinical experience primarily with individuals with stroke. All of the convenience-sampled clinicians were female. The sample was evenly divided between occupational therapists and physical therapists. The clinicians were asked about the type of exercises that they prescribe for home exercises. Figure 2 shows the reported incident of prescribed home exercise themes, which primarily focused on functional activities and strengthening. On average the clinicians estimated that 50% of their patients are compliant with home exercises.

4.1 Game Feedback

Only two of the twelve clinicians had previously used the Kinect, and each of these clinicians had only used the Kinect once. The clinicians generally felt that the programs had good usability as shown in Figure 3. All of the clinicians felt that this system would be helpful for home exercise of individuals with

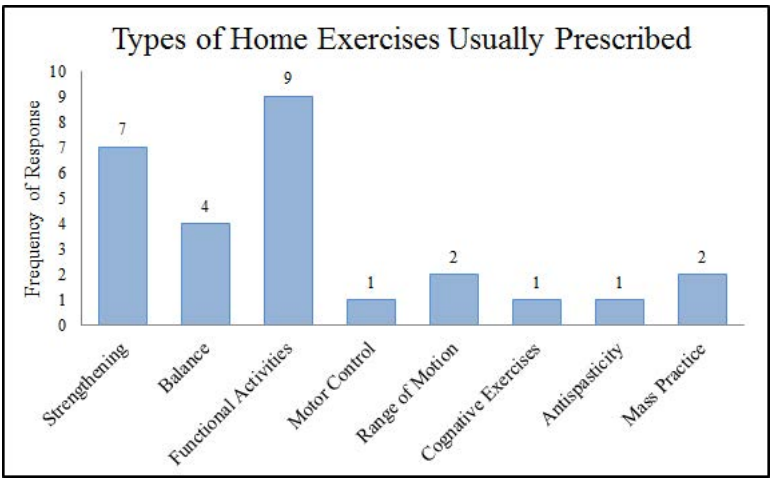

Fig. 2. Clinician prescribed home exercises by frequency reported. Upper extremity was not specified in the question. The functional activities category includes gait, and mass practice includes constraint induce movement therapy.

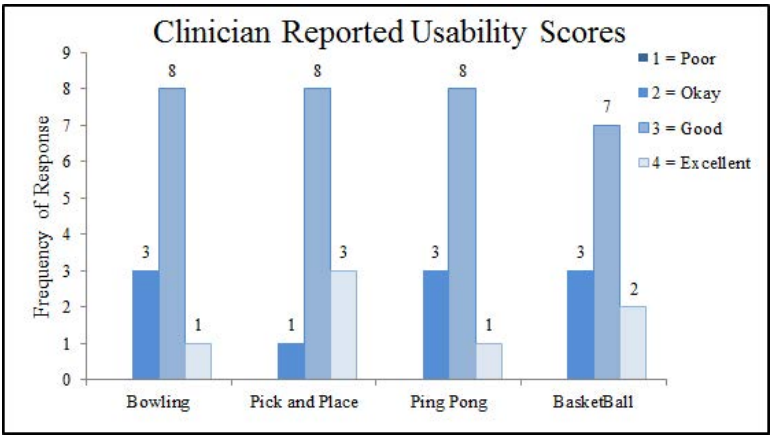

Fig. 3. Frequency chart of clinician reported usability showing the median score of good(3) for all of the tasks

stroke. Eleven of the clinicians found the physics based games (Ping Pong and Basketball) to be more entertaining than range of motion tasks like Bowling. The clinicians were divided about the need for the games to be functional task focused. Four desired games modeled after functional tasks, another four desired a mix of game and functional tasks, and the final four said game based. Two supporters of the game based design mentioned that the games should still have functional movement goals. The majority of clinicians (10/12) felt that task difficulty should be varied within each game instead of between sessions. Ten

clinicians felt a mix of seated and standing exercises would be best. Several clinicians had a caveat to their answer, that this would only be true in situations where standing safety was not a concern. One clinician mentioned that special consideration of sitting balance should be made when choosing game reaching targets.

In Ping Pong two users were confused by the avatar's inability to interact with the ball. Another user found the variable timing aspect of the game, the ball speeds up with a hit and slows down with a miss, confusing. In general questioning, only two of the users reported that they found the avatar distracting or confusing. Having the avatar present, even when it isn't interacting with the virtual world, is helpful to show users what the Kinect sees, since occasionally the Kinect can have trouble with skeleton tracking.

4.2 Commonly Reported Limitations

Although the Kinect sensor has occasional limitations in tracking ability, the clinicians were generally very tolerant of the minor tracking errors that occurred during testing. The main reported concerns are shown in the Figure 4. The majority of these concerns are relatively self-explanatory. The readability was the main concern reported by the clinicians. A few individuals reported concerns about the graphics simplicity, including the "amputation" of the lower extremities of the avatar. The lower extremities were removed because the Kinect cannot accurately track their position while the user is seated. Clinicians also reported the desire to include tasks with wrist supination/pronation (6 users), grasp motion (4 users), and isolated shoulder horizontal abduction/adduction (3 users). Unfortunately, the Kinect is unable to detect supination/pronation of the wrist, nor can the Kinect cannot detect finger movements with the current skeleton tracking method, so additional sensors would be needed for these tasks.

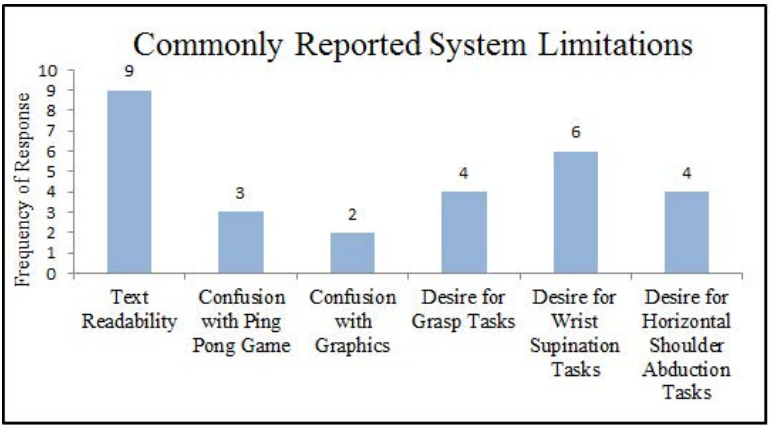

Fig. 4. Frequency of the reported limitations of the HAMSTER system

4.3 Compensation Strategies and Measurement of Kinematics

As stated previously, the use of compensation strategies limits the active use of the affected arm and thus reduces recovery from therapeutic interventions. When clinicians were asked about common compensation strategies that should be minimized during training, trunk movement was listed seven times, shoulder hiking three times, shoulder internal rotation two times, and shoulder abduction with elbow flexion two times. Unfortunately, the Kinect does not have the resolution to detect shoulder hiking. However, the Kinect is able to monitor trunk position, shoulder internal rotation, and shoulder abduction. The Bowling game already provides feedback to limit horizontal shoulder abduction and elbow flexion during the task.

It was originally thought that the kinematics recorded from the clinicians would serve as control data. However, many clinicians simulated movement patterns common to individuals with stroke during portions of the system testing. The Bowling game data is discussed here to show how the system will be able to track the movement of individuals with stroke during training. The researcher observed that the clinicians commonly tested trunk compensation patterns during Bowling. Although trunk deviation was higher in Bowling than in the other games, the subjects' average trunk angle was only 5.3 degrees from vertical with an average standard deviation of 4.7 degrees, showing that, in general, the individuals had relatively good posture when completing the task. The goal of the Bowling task is shoulder elevation with elbow extension. As a result, the maximum coordinated shoulder and elbow position that the user is able to obtain during Bowling is a measure of the user's ability to move out of the flexor synergy, which commonly impedes movement after stroke. The clinicians' average maximum coordinated position (highest shoulder angle with the elbow at less than forty degrees of flexion) was 17 degrees of elbow flexion and 138 degrees of shoulder flexion. Since the elbow error was set at 40 degrees of flexion, 17 degrees is reasonable, but shows that the clinicians did not maintain full elbow extension during the movement. This kind of quantitative data will be useful in tracking the therapy progress of individuals with chronic stroke.

5 Design Modifications and Future Work

Many simple changes to the HAMSTER system have been implemented based on the clinician feedback. The words on the screen have been reduced in number, and modified for size and clarity. Based on feedback from clinicians, HAMSTER now provides visual feedback to attempt to reduce user's trunk movement. This feedback does not limit task progression, but could for more advanced users. It is difficult to provide meaningful feedback about shoulder internal rotation since it may be used in normal movements. Feedback from testing with individuals with chronic stroke will determine how and if this kind of feedback is required for the HAMSTER games. In general the graphics were kept simplistic. The avatar has been modified to include a chair with the lower extremities to eliminate the confusion reported by one clinician. The Pick and Place task was modified

to better represent a function task (feeding a fish) since integrating functional goals was encouraged by the clinicians. The Basketball game was renamed Darts, and the graphics modified to better describe the actual physics of the game and reduce confusion. An additional game was created focusing on shoulder abduction with a physics based design since clinicians found that game model more entertaining. The modified graphics for Fish, Darts, and Bird are shown in Figure 5. System usability and viability testing with individuals with chronic stroke related disability of the upper extremity is pending.

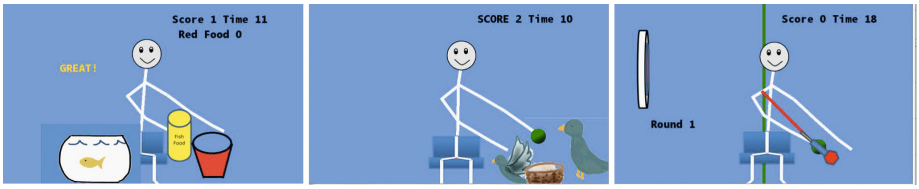

Fig. 5. The images show the modified graphics including the minimized and enlarged words, and the thicker lined skeleton with a chair. The far left image shows the modified Pick and Place task now named Fish. The middle image is the new Bird game. The user adducts/abducts their shoulder to move the mother bird to catch the baby bird. The third image is the modified Basketball game, which is now called Darts.

6 Conclusion

The results from these focused interviews have shown promise that HAMSTER will be usable and therapeutic for individuals with stroke. All of the clinicians felt that the system would be beneficial to individuals with chronic stroke. In general, the Kinect system was fairly intuitive, as noted by the good usability scores. This is especially impressive considering the users' very limited previous exposure to the Kinect. The kinematic data provided continuous and reasonable measures of arm and trunk movement. The changes discussed in future work will help improve the system effectiveness.

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