Games for Physical Therapy

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ABSTRACT
One in six people in the world will experience a stroke in their lifetime. A large proportion of these survivors will have motor impairments as a result of this. Physical therapy can help stroke sufferers to overcome these limitations. Research suggests that the brain can be provided with sufficient stimuli to remodel itself and to provide better motor control through repetitive exercises. However, several hundred daily repetitions may be required to make recovery progress, a figure that is larger than the number of exercises in a typical therapy session. Therapists overcome this by prescribing home exercises as a component of outpatient therapy. However, patients often find the repetitive exercises boring and less than a third of people perform them as recommended. Other common rehabilitation problems include high healthcare and travel costs to attend clinic sessions. An alternative way to complete prescribed home exercises is to leverage interactive technologies such as video games with motion-based input devices. Motion-based games help to increase the likelihood that a patient will complete therapeutic exercises at home by using a game context to motivate the patients. The scope of this paper is to explore the interactive technologies that are used to develop these games, and their value in the context of stroke rehabilitation. The games will be evaluated from both a result focused perspective and patient usability perspective.

Author Keywords
Stroke, physical therapy, rehabilitation, video games, serious games

INTRODUCTION
Stroke is one of the leading causes of motor impairment in a number of countries such as the UK, Canada, United States and Singapore [2, 3, 5, 8]. A stroke typically occurs when blood flow to a portion of the brain is congested by a blood clot, causing the blood deprived brain cells to die within minutes. Depending on the locality and severity of damage to the brain tissue, the stroke sufferer is likely to experience cognitive, visual and motor losses. Studies have suggested that up to 80% of these survivors will have significant motor impairments as a result of this [4]. These impairments will impact the sufferer's independence by impeding their ability to perform basic daily activities such as driving, cooking, housekeeping, bathing, dressing and eating [5].

Physical therapy can help stroke sufferers to overcome the limitations they experience. Research with animal models suggests that the brain can be provided with sufficient stimuli for neural reorganization of the cerebral cortex [5] through repetitive exercises. It may even be possible for stroke survivors to recover to motion levels close to normal. However, several hundred daily repetitions are required to make recovery progress, a figure that is larger than the number of exercises in a typical therapy session [3].

Therapists overcome this by prescribing home exercises as a part of outpatient therapy. However, patients often find the repetitive exercises boring, resulting in only 31% of people performing them as recommended [4]. As recovery often happen in stages, it is easy for patients to lose confidence in their recovery process after not observing any improvements over a long period of time [3]. Another common rehabilitation problem faced is high healthcare costs due to the treatment being administered on a one-to-one basis, and the need for the patient to travel frequently to clinics to attend therapy sessions.

An alternative way to complete prescribed home exercises is to leverage interactive technologies such as video games with motion-based input devices. Motion-based games help to increase the likelihood that a patient will complete therapeutic exercises at home by providing a rich graphical and multimodal game context to motivate them [5]. The games themselves also have the potential to be customizable to suit the individual patient undergoing stroke therapy [6]. It is anticipated that through providing a game context to decrease the monotony of hundreds of repetitive motions, and giving encouraging performance feedback, both the quantity and quality of home therapy will improve [4].

The scope of this paper is to explore the interactive technologies that are used to approach the development of games for upper limb rehabilitation and game design theories. The value of games trialed will be evaluated from both a result focused perspective and patient usability

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perspective in the context of stroke rehabilitation.

PROBLEM SPACE AND APPROACHES

The usage of games for stroke recovery can be broken down into four main sub areas: The underlying technology used for game development, game design principles, daily need of people with stroke at home, and the use of collected game data for motion assessment purposes. These are discussed in detail below.

Technologies Used

The technology used to interact with stroke patients has a major impact on the practicality of using games for physical therapy at home. This is because the technology itself dictates inherent properties such as usability, affordability, enjoyability, and the type of movements supported by the system. A variety of potential post stroke rehabilitation technologies were explored.

Virtual reality is used for supporting hand and arm tracking and gesture recognition. To track the user's limb position and orientation, electromagnetic sensors are attached to the user to generate data in real time. A graphical avatar is often created in the virtual environment based on user input data to achieve user immersion [5]. Data gloves (with or without force feed-back) enable gesture recognition through the tracking of finger and hand movements, which can then be used to train specific hand movements [1, 2, 8]. To further increase the patient's sense of immersion in the virtual environment, a head-mounted display could be worn. A disadvantage of using the above sensors is the amount of fixed technology worn, which is a potential source of problem for users with physical impairments in terms of putting on the equipment and user comfort [5].

Augmented Reality that uses head-mounted displays has also been explored in the use of creating therapeutic games [2]. This involves the rendering of virtual objects onto a captured scene in the real world. A major advantage of augmented reality is the ability to manipulate real world objects in a simulated environment. This interaction provides a more direct mapping to the tasks a patient has to perform in his or her daily life. Through manipulating real objects, the user is able to get accurate haptic feedback from performing the tasks required. However, a drawback with this system is that the perception of depth using the head mounted display is difficult.

Video-capture technology offers an alternative method of tracking user's movements. An example is the GestureTek IREX system, which is able to track user limb movements through using a camera, and color detection software to follow the motion of a coloured glove worn by the user [3, 5].

Another alternative is the use of commercially available video game console platforms such as the Sony Eye Toy, Nintendo Wii and Xbox Kinect. These gaming consoles are generally much cheaper than specialist virtual reality and video capture systems and are relatively easy to set up and use without the aid of a technical expert. Since the release of Microsoft XNA Game Studio Express in 2007, the cost of developing games on commercial consoles has decreased dramatically, offering the potential for custom tailored games to be developed [5, 8].

Game Design Principles

Another important aspect of leveraging games for physical therapy is the theories behind the design of games in a rehabilitation context. Initially, commercial motion input games with potential for stroke rehabilitation were examined by the therapy community [4]. Although console games such as the Wii Sports are helpful for stroke patients in later stages of recovery, they could not be used for the majority of recovering stroke patients, as the games were designed for users with a full range of motion. Consequently, researchers looked to develop their own games to assist in the early stages of stroke recovery. As the number of tailor made games increased, research has naturally progressed to identify and discuss the desirable properties in the design of rehabilitation games.

One such property is the principal of meaningful play suggested by Burke et al [5]. Meaningful play comes from the relationship between the user's choice of actions and the systems response, such that a player is able to perceive the influences of their action upon the game play. This is typically achieved through providing feedback. Feedback, which can be aural, visual or haptic, enables the user to measure their progress and success in achieving a goal. Quantifiable advantages for successfully completing specific tasks are great incentives that can lead to motivation and enjoyment. However, failures should be dealt with delicately in the rehabilitation context in a positive way to keep rehabilitation players engaged.

Another important aspect to consider is the challenge of the game [5]. The difficulty of the game should be able to be adjusted to suit the condition of individual players with different motion abilities. One such method to achieve this is to calibrate the game based on example motion and occasionally requiring the player to extend a little beyond their initial range [4]. Game speed, game element sizes and position should all be customizable. During game play, the player gains familiarity with the game element and goals and thus will generally perform better. To maintain a suitable degree of challenge, the game should also automatically adjust the difficulty of play to prevent player boredom throughout the game session [5].

Patient Needs at Home

Home-based rehabilitation game systems are faced with additional challenges [3]. Firstly, the user population is likely to be the elderly and may have fewer experiences interacting with technology than regular computer users and game players. In addition, potential therapeutic game users

have motor impairments, which will limit their ability to interact with the home-based game system. Therefore, the software and additional equipment used need to address human factors appropriately.

Existing research [3] has identified some insights, issues and challenges through the use of simple prototypes in organized workshops with therapists and stroke patients. Guidelines exist to: consider the wider social context of living with stroke, the capacity for games to be personalized, the ability to manage the time and length of game sessions, to detect improvements that occur in an unsupervised home setting, and providing appropriate feedback to users. However, little research addresses the long-term use of such game systems. A thorough user-centric understanding of this interaction between stroke patients and home based systems over time is crucial for developing effective therapeutic game systems for long term use.

Game Data for Motion Assessment

Many researchers have observed that standard motion assessments used in therapeutic practices may not be able to fully capture motion improvements of game players [3]. Precise kinematic data captured from exercises are typically used for motion assessment with accelerometers being the main use for overall measurements such as energy expenditure and predicting clinical scores. In comparison, game data supplied by technologies such as Wii remotes and web cameras are much less descriptive and harder to utilize for motion assessment techniques. However, data related to game play can provide valuable information on the user's intent. Combined with data from the sensors reflecting the user's motion, motion competency can be calculated. Such data can be easily stored for later retrieval and analysis by both the patient and their therapist [1, 3, 5].

METHODOLOGY

Participants

All studies recruited elderly post stroke patients between the ages of 40 to 80. These participants were at least one-year post stroke where major motor improvements were not expected. This was to avoid interfering with current best practice therapy approaches that may risk the recovery process of the patient. Chosen participants were also not participating in any other rehabilitation programs that may have interfered with the validity of motor data collected.

In short-term studies on proving the feasibility of specific rehabilitation systems and games [1, 6, 7], groups of three to six participants with varying degrees of motor impairments were recruited to participate in the study. Long-term studies typically only focused on one participant. Participants had to be able to demonstrate enough motor capabilities to use the system to qualify for the study.

Studies on the playability of games [5] use an iterative approach that initially begins with conducting the study with a group of able-bodied users. Subsequent phases then recruit post stroke patients to participate in short, once off sessions.

Game Infrastructure

Game Hardware

The game hardware used in the studies largely depended on the target rehabilitation movement. A common theme was the use of virtual reality and augmented reality to immerse the user in a game environment.

Studies that targeted the rehabilitation of finger and hand movements commonly used data gloves to collect user input data. The games were then displayed using a head-mounted display with virtual objects overlaid on top of the real scene. The user interacted with the game through finger and hand movements such as flexing their fingers to generate game events [8].

In contrast, studies that focused on arm movements tended to use commercial game technology in conjunction with a standard web camera to capture video data of a user's movement [3, 5]. Output was displayed through the rendering of game elements to any PC display device, typically a standard computer monitor.

Game Software

The games were designed to promote gross movement in the targeted area. The majority of these games will have taken the game design principles into account and can be played either sitting or standing.

Games that are aimed at recovering arm movements [5] can either be single arm or bimanual rehabilitation. The player controlled game elements by moving his or her arms to achieve a goal. This movement can either be tracked using hardware such as the Wii Remote [3] or color detection software [6] to track a colorful glove worn by the user. Besides encouraging arm movement, the games also aimed to improve the accuracy and speed of user arm movements.

In comparison, games aimed at recovering finger and hand movements [1, 8] focused on a single parameter at a time: either fractionation, speed of movement, range or strength. Therefore the user was only able to use a limited range of motion to interact with the software. Thus games designed for hand rehabilitation typically had a different look and feel compared to games for arm rehabilitation.

Most game software also supported user profiling, which allowed user information to be saved and enabled customization through providing game settings. An example of this was the ability to select the adaptive difficulty mechanism option, which would automatically

adjust game difficulty based on user's performance in the game [5].

Game Play

Set up

In the home studies [3], the user was expected to set up and calibrate the game through the use of game launcher from a menu. Calibration involved example motion to outline the user's motion range.

Program

Participants were asked to play the games exclusively in the respective environment studied for 1-2.5 hours daily, 5 days a week, for a total of up to 6 weeks.

Data

Participant experience and feedback data was collected through post study questionnaires and interviews [3, 5, 7]. These had a focus on the participants' self-evaluation of the games based on the following: perceived exertion, challenge, usability, and general game play experience.

In-game data was recorded by the system and saved [1, 3, 5, 6]. This information included both data generated by the input devices as well as game event data. The collected data allowed for later analysis to identify duration of game play, possible improvements in skill and movement and problematic areas to provide appropriate feedback.

In addition, standardized tests (Action Research Arm Test, Reaching Performance Scale and Jebsen Test of Hand Function) were used to measure the difference in the participants' range of functional performance and range of motion [1, 3, 6, 7].

FINDINGS

Therapeutic Measures

Overall, participants in studies of three weeks or longer showed improvements in their range of motion and motor control [1, 3]. Individually, participants demonstrated a varied degree of improvement that was not necessarily seen across all other individuals in the group who participated in the same study.

The participant who played arm rehabilitation games for six weeks found that she could raise her affected shoulder higher and had a larger range of shoulder movement. Finger and thumb range motion were increased in participants who played the finger and hand exercise games. However, there was no significant group improvement in the speed of finger and thumb movements.

Game Data

Overall, all participants who participated in studies of three weeks or longer showed improvements in their performance in game play and were able to score higher [1, 3, 7]. Data from input devices showed that players had a greater range of motion at the end of the study. By comparing motion trajectories with the game elements, improvements in motion precision were identified. It was also noted that arm movements were smoother indicating increased motor control.

User Feedback

All participants found the therapeutic games easy to learn, sufficiently challenging and rewarding to play [3, 5, 6, 7, 8]. Most participants expressed an interest in owning a copy of the games to play at home on a daily basis.

In the playability study [5], users were asked to evaluate the games based on the user interface, length of game, game feedback and enjoyment. All games were found to be highly enjoyable, with appropriate and responsive feedback. The user interface was clear, consistent and well organized and game length was suitable. However, the adaptability feature of the games was found to be aggressive and players preferred to be able to set the difficulty themselves.

In long-term study sessions [3, 7], post-study questionnaire results showed that most participants enjoyed partaking in the therapeutic games and believed that their arm and finger functions improved. One participant in a six week long study reported discovering new abilities in her daily life around three weeks into the study. Participants also showed an interest in collaborative games that they could play with other stroke patients or family members.

SUMMARY

Stroke is the leading caused of physical impairment in the population. Motion input games have proven to be feasible in the use of therapeutic treatment for stroke survivors. Games targeted at upper limb rehabilitation have shown potential in terms of both therapeutic value and patient enjoyment. Some hardware devices were explored further than others and the emerging trend tends towards the use of cheap devices in home-based therapy. Game design principles have been established but there is still a lack of high quality games developed for therapy especially in the area of collaborative games.

FUTURE WORK

Several directions for future research were uncovered through the review of current research. It became evident that most research studies were carried out under very limited time frames and were narrowly focused.

While current case studies show promising recovery results, further research is required to confirm this. More participants are needed for extended game rehabilitation to refine existing games and game systems in terms of usability, therapeutic value of game input movements and long term use and benefits.

Future game development direction should focus on incorporating typical motions within a clinical therapy

session. Games should also be highly customizable to be tailored to the personal situation of individual players. This means that in addition to existing principles, games should also have a wide variety of themes and support both individual play and collaborative play.

REFERENCES

1. Adamovich, S., Boian, R., Burdea, S., Lewis, J., Merian, A., Poizner, H., Recce, M., Tremaine, M. A Virtual Reality—Based Exercise System for Hand Rehabilitation Post-Stroke
   Conf. IEMBS 2004, Presence (2005), 161-174
2. Alamri, A., Jongeun C., Saddik, A. AR-REHAB: An Augmented Reality Framework for Poststroke-Patient Rehabilitation

   Instrumentation and Measurement (2010), 2554 – 2563
3. Alankus, G., Engsberg, J, Kelleher, C., Proffitt, R., Stroke Therapy through Motion-Based Games: A Case Study
   Proc. Assets 2010, ACM Press (2011), 1-35
4. Alankus, G., Kelleher C., Lazar, A., May M. Towards customizable games for stroke rehabilitation

   Proc. Human factors in computing systems 2010, CHI (2010), 2113-2122
5. Burke, J., Charles, D., Crosbie, J., McDonough, S., McNeill, M., Morrow, P. Optimizing engagement for stroke rehabilitation using serious games
   Proc. Augmented Human International Conf 2011, The Visual Computer (2009), 1085-1099
6. Charles, D., Crosbie, J., Oliver, L., Ma, M., McDonough, S., McGoldrick, C., McNeill, M. Adaptive virtual reality games for rehabilitation of motor disorders. Ambient Interaction (2007), 681–690 (2007)
7. Lewis, G., McPherson, K., Rosie, J., Woods, C. Virtual reality games for rehabilitation: Perspectives from the users and new directions

   Conf Virtual Rehabilitation 2011, 1 - 2
8. Nee, A., Ong, S., Shen, Y., Zhang, D. An Affordable Augmented Reality Based Rehabilitation System for Hand Motions

   Conf Cyberworlds 2010, 346-353