Opportunities in Game-Based Stroke Rehabilitation

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Abstract—**Stroke is the most common cause of long-term disability of adults in developed countries. Continuous participation in rehabilitation can alleviate some of its consequences, and support recovery of stroke patients. However, physical rehabilitation requires commitment to tedious exercises routines over lengthy periods of time, which often causes patients to drop out of therapy routines. In this context, game-based stroke rehabilitation has the potential to address two important barriers: accessibility of rehabilitation, and patient motivation. This paper provides a summary of design efforts in human-computer interaction (HCI) and games research to support stroke rehabilitation. Based on our review, we discuss challenges and opportunities in game-based stroke rehabilitation, and outline areas for future work that need to be addressed to offer engaging game-based stroke rehabilitation.**

Keywords—video games; stroke rehabilitation; video games design; games for health; motivation; human-computer interaction

I. INTRODUCTION

Stroke is the sudden death of brain cells in a localized area due to inadequate blood flow; it is the most common cause of long-term disability of adults in developed countries. Consequences of stroke include visual, cognitive and motor losses, some patients may lose both memory and speech: Up to 85% of stroke patients suffer from hemiparesis – weakness on one side of the body – and between 55% and 75% of survivors experience motor deficits; conditions such as hemiplegia – paralysis or weakness on one side of the patient's body including loss of control over one leg – can result in a physical disability that makes walking difficult or impossible. Often, these issues substantially limit an individual's abilities of interacting with the world, and reduce their ability of leading an independent life [1, 2]. In this context, increased dependency on the care of others negatively influences the physical and emotional well-being of stroke survivors, and has a negative impact of their quality of life [3].

Fortunately, rehabilitation and continuous participation in occupational therapy can alleviate some of these consequences, and support the recovery and independence of stroke patients. However, particularly physical rehabilitation often requires commitment to tedious exercises routines over prolonged periods of time [4]. Many of stroke patients could recover some physical functioning by performing hundreds of daily repetitions of motions with affected limbs [5]. Effective rehabilitation programs initiated early after stroke can improve the recovery process and minimize functional disability [6], but rehabilitation programs are expensive and labor intensive, and unavailable to patients in remote areas. In addition to these access barriers, patients that do enroll in rehabilitation programs often do not follow through with therapy routines, leading to high dropout rates and a loss of potential benefits.

There are technologies that have the potential to address these two main issues, accessibility of rehabilitation, and patient motivation [1, 7]: computer-based stroke rehabilitation can be carried out in the patient's home independently while reducing treatment costs and increasing its accessibility for patients with mobility disabilities or those living in remote areas. Additionally, game-based solutions offer the potential of integrating playfully challenging elements and external motivations into therapy routines, thereby increasing patient inspiration to follow through with previously tedious tasks [5].

This paper provides a summary of design efforts in human-computer interaction (HCI) and games research to support stroke rehabilitation. We study existing cases in the field of game-based stroke rehabilitation (e.g., the development of motion-based video games particularly addressing rehabilitation among stroke patients [5, 8]). We discuss the effectiveness of such approaches by integrating findings from medical research that considers health outcomes of game-based stroke rehabilitation. Based on these results, we discuss challenges and opportunities in game-based stroke rehabilitation, and we outline areas for future work that need to be addressed to offer game-based rehabilitation to broad groups of stroke patients.

We believe that further exploring design opportunities in the field of game-based stroke rehabilitation is an important step toward the creation of games that are accessible, motivating and enjoyable for stroke patients; only if games can provide empowering experiences for patients while offering options to be effectively managed by medical staff, they can be adopted into medical practice and contribute to patients' recovery from stroke.

II. LITERATURE REVIEW

A. Rehabilitation Games

Technology-based rehabilitation has been highlighted as an opportunity for in-home rehabilitation that would allow patients to continuously engage in therapy even after being discharged from a hospital, moreover would make therapy more accessible for persons living in remote areas.

In this context, research in the area of stroke rehabilitation systems suggests that maintaining patient motivation is an important step towards ensuring therapy success; however, poorly designed and implemented technology-based rehabilitation is often tedious, repetitive, and does not provide

encouraging feedback, hence leading to a significant reduction in patient motivation.

Case studies have shown that games and similar technologies have the potential to provide significant external motivation for stroke patients. Hence, the greater the motivation to participates in rehabilitation tasks, the more likely they will continue active participation. Similarly, longer therapeutic sessions could lead to greater functional outcomes over the course of treatment [9]. Hence, home-based stroke rehabilitation games may help motivate stroke patients to perform the necessary exercises [5]. By decreasing monotony of repeated motions and providing performance feedback, these games are designed to help patients in recovering from a stroke. To have the maximum impact, these games must ensure that patients are correctly performing therapy motions and also provide a motivating context for therapy. It is also suggested that games which provide a sense of social connectedness with other stroke patients may help decrease patients sense of isolation and increase their motivation to exercise [5].

B. Background

In the middle of 1970s, Bach-y-Rita et al. [1] adopted the newly introduced electronic pong games for the functional training for hemiparesis limb patients. Their customizable input controllers were developed to match with the varying grips of the stroke patients for use with a modified exercise track. The second version of the pong-game device consisted of an actuator/sensor sliding lever, where the lever was attached to a "trolley car" that rolls on ball-bearing wheels inside a wooden box.

Flores et al [9] studied different systems that implemented games-base rehabilitation, for example, Goude et al., present a model for game design in general based on the association between gaming patterns and the taxonomy of stroke rehabilitation. In this model, only a subset of stroke symptoms and treatments were discussed which suggests the need to expand the analysis of the taxonomy and to verify the associations between game patterns and treatments. As another example, Colombo et al. focused almost on the motivation of the users of a specific robot-aided rehabilitation system, called Two-Dof, using the Intrinsic Motivational Inventory questionnaire. They created a simple game in which the patient tried to move a colored circle from an initial position to a goal position using a robotic device designed for arm rehabilitation.

In more recent studies, Alankus et al [5] reviewed games that were developed to assist stroke patients in earlier stages of recovery, as such the development of haptic glove based games to improve the player's finger flexion and extension, where players could scare away butterflies, play the piano, and squeeze virtual pistons. Broeren et al. [10] created several 3D games for use with a pen-like haptic device. Burke et al. built two webcam color tracked games similar to whack-a mole. Yeh et al. [11] developed a series of 3D games involving manipulating objects. Sanchez et al. [12] developed training exercises modeled on everyday tasks.

Following to the review of some existing stroke recovery games, Alankus et al. [5] developed a series of games using various input devices (see Table 1 – next page). Their games aim to measure the effectiveness of different approaches by having different goals and differing from being single or multi-player, cooperative or competitive, and requiring more or less cognitive challenge. For example, *Frog Simon* is a single-player game that requires a precise input although also providing a level of challenge on memory; while *Dirt Race* is a simple two-player cooperative game that requires basic inputs and goals.

In other similar efforts, Todorov et al. [13] used a virtual reality system for two player table-tennis training. Patients with hemiplegia were trained in a virtual. One of the subjects showed clinical and functional motor improvements and the second showed no improvements. Shin et al. [14] developed a system called RehabMaster that is a feasible and safe VR system for enhancing upper extremity function in patients with stroke. A Kinect-based system by Chang et al. [15] used as a rehabilitation tool for children with acquired muscle atrophy and cerebral palsy. Ustinova et al. [16] made a 3D videogame that could enhance arm postural coordination in traumatic brain injury patients.

Based on the review of existing design efforts in the field of game design for stroke rehabilitation (see Table 1 again), we summarize the most important benefits of game-based stroke rehabilitation, and identifies promising design opportunities that are associated with social and medical aspects of stroke rehabilitation.

III. REHABILITATION GAME DESIGN OPPORTUNITIES

A. Benefits of Game-Based Stroke Rehabilitation

This section discusses benefits of game-based stroke rehabilitation by relating efforts in the fields of human-computer interaction and games research to medical research.

1) Increased Patient Motivation and Engagement

Previous works in the field of game-based stroke rehabilitation aim to leverage the motivational power of games to increase patient commitment to follow through with therapy routines. Follow-up studies have demonstrated the effectiveness of games in this respect, showing that systems that have focused on factors such as entertainment are able to achieve increased engagement [1, 5, 7, 17]. For example, the study of Bach-y-Rita et al. [1] presents a system that using the context of a digital game proved to be efficient in entertaining the users. Such entertaining systems may help users to be more focused on games' goals, rather that paying attention to the repetitive motions patterns, potentially achieving better progress on their recovery.

The required movements in stroke rehabilitation for the recovery of affected limbs involve a high amount of repetition, which can quickly become a boring and uninteresting activity for patients [4]. However, the concern around increasing the patients motivation on performing these exercises have not received enough attentions [1]. One reason might be the great diversity of stroke types and effected brain areas, which makes it difficult to design a single system that can effectively cause engagement for a large number of different users.

Table 1 – Summery of game-based stroke rehabilitations

Author	Application name	Description
Bach-y-Rita et al.[1]	Pong V1	Competitive Sports Game, can be played either single-player against an AI or Multiplayer, using a Modified hand joystick
	Pong V2	Competitive Sports Game, can be played either single-player against an AI or Multiplayer, using a Sensor sliding lever
Jack et al.[18]	VR Rehab System	Single-player Exergame using a CyberGlove and RMII Glove
Broeren et al.[10]	VR Activity Station	Single-player collection of different games using a Pen-like haptic device
Burke et al.[8]	Rabbit Chase	Single-player casual Action Game using a Webcam
	Arrow Attack	Single-player casual Action Game using a Webcam
	Bubble Trouble	Single-player casual Action Game using a Webcam
Yeh et al.[11]	Various	Single-player collection of different games using a Force Feedback Devices and Tracking System
Sanchez et al.[12]	Java Therapy 2.0 Games	Single-player Simulation Game using a Modified passive antigravity arm orthosis and Grip sensor
Alankus et al.[5]	Frog Simon	Single-player Puzzle Game using a Wii Remote Controller and Webcam
	Dirt Race	Cooperative Multiplayer Driving Simulation Game using a Wii Remote Controller and Webcam
	Baseball Catch	Single-player Casual Action Game using a Wii Remote Controller and Webcam
	Catch the Kitty	Competitive Multiplayer Casual Action Game using a Wii Remote Controller and Webcam
	Under the Sea	Cooperative Multiplayer Casual Action Game using a Wii Remote Controller and Webcam
	Pong	Competitive or Cooperative Multiplayer Sports Game using a Wii Remote Controller and Webcam
	Frogger	Cooperative Multiplayer Casual Action Game using a Wii Remote Controller and Webcam
	Helicopter	Single-player Side-Scrolling game using a Wii Remote Controller and Webcam
	Garden	Single-player Simulation Game using a Wii Remote Controller and Webcam
Todorovet et al.[13]	Table-tennis	Cooperative Multiplayer Sports Simulation Game using Paddles and Electromagnetic sensors
Shin et al.[14]	RehabMaster	Single-player collection of different games using OpenNI™-compliant 3D depth sensor
Chang et al.[15]	Kinerehab	Single-player Exergame using Kinect
Ustinova et al.[16]	Octopus	Single-player casual Action Game using a 6-camera system

B. Lower Access Barriers to Rehabilitation

As mentioned earlier, another concern related to stroke rehabilitation is the fact that it demands time and resources. Depending on the severity of the condition, the recovery process can take from weeks to years of constant daily practice of hundreds of exercises. In consequence of this, the treatment goes beyond the rehabilitation centers and patients receive a large amount of the responsibility on continuing the treatment at home [4]. Various studies showed that the clinical recovery period is often effective, however, it is slow or inefficient for most patients when the recovery continues at home, mostly due to the fact that just a small number of patients perform the exercises in the recommended way [5]. Keeping this in mind, it is important to find a solution that is not only reasonable for rehabilitation centers, but also affordable for most common residences. With the advancement of digital technology, there are more opportunities for cost-efficient digital systems to be used as supporting tools in rehabilitation, such as cameras, sensors, computers and video games. They are, however, required to be adapted in order to fulfill the needs of the rehabilitation plan [9].

C. Design Opportunities in Game-Based Stroke Rehabilitation

1) Patient autonomy and Multiplayer

The vast majority of patients affected by stroke eventually become severely dependent on family members or friends. Due to motor, cognitive and visual problems, there are few patients who can return to their full-time work, or perform common activities of daily life, such as eating or dressing with ease [5]. Therefore, it is important to consider a patient's autonomy when designing rehabilitation systems. This can be mainly reflected on making users to feel in control when using the system. For example, games with multiplayer functionalities may offer a cooperatively or competitively setup that can be used by families, friends or even other affected patients [4, 5]. However, it is important for the systems to provide a possibility for an individual use, thus respecting their autonomy for not being dependent on others. It is also possible to balance between a cooperative scenario, where affected patients can play as a supportive role limiting their interaction with the game goals, or a competitive scenario, where they can feel an unfair competition.

Due to the diversity of affected limbs and the severity of stroke, it is not possible to design a game that aggregates all users. However, this issue can be softened through customization tools. The ideal situation could be to have the involvement of a physiotherapist to perform initial customization of the system, entering the necessary levels of precision, speed and other relevant factors, focusing on the needs of each separated patient [5]. Moreover, it is important for the game to offer some sort of adaptability functions that can be fully automatic or manual. As with the progress of the training, the patient's performance tends to improve, there should be an intelligent system to perceive the user's progress and automatically adapt its difficulty, or may have pre-sets of different levels that the patients can change when they feel the need. This adaptability is a vital important to help the patients' recovery and maintaining their interest in the game [5, 9].

2) User progress, feedback and Information

One of the main advantages of using digital systems to assist with rehabilitation practices is the potential of the system's interaction with the user, such as the ability to save and present users' progress to provide them with specific and targeted feedback. For example, following Nicholson [19], a

simple use of a visual system showing body areas that are getting improvements due to the performed activity may increases motivation and the development of personal goals. Moreover, some patients may not feel motivated to perform certain activities or motions due to the lack of understanding on the benefits or perceiving progress [3]. Early introduction of relevant information prior to playing showing the rehabilitation objectives of each exercise could helps avoiding discouragement (due to the lack of information) and provides greater ease on creating new personal goals.

3) Diversity and Flexibility of Content

As mentioned before patients affected by stroke are a wide target audience, hence there is also a challenge on making design decisions when designing a single rehabilitation system that uses entertainment as one of the key pieces to provide user engagement [4]. One possible solution is to focus on the diversity of content. A game having different kinds of mini-games with different gameplay experiences can attract players that have different profiles with specific preferences. Furthermore, diversity in content also may increase the amount of different options that each user has to practice, preventing boredom with a single game. The topic of content diversity was also observed in a study in which a system of book reader for a stroke patient was efficient at the beginning, but as it contained as just a single book it quickly turned out to be disinteresting, failing to engage the user over longer period of time [4].

4) Rehabilitation Exercises

The system needs to be designed in a way to perceive with precision when users performing the necessary motions. The help of a physiotherapist is necessary together with the development team to effectively design the right motions and mechanics [5]. The system must be precise on the way it track users performing motions, preventing users from incorrect or inadequately performances [5]. It is also important to prevent users on exaggerating the amount of needed exercises, hence another opportunity when using a digital system is the potential of giving feedback about the necessary training intensity to achieve the best recovery progress through the activities [18].

IV. Conclusion and Future Work

This paper provides a summary of game-based approaches to support stroke rehabilitation from the perspective of game design. From reviewing studies and implemented stroke rehabilitation games, we showed that a combination of mental supports, self and external motivation, and accessible interfaces are important consideration for designing game-based rehabilitation. It is important to emphasize that playing games at home can be done anytime and potentially empower patients to take ownership of their therapy.

One potential development could be to leverage motivational pull of commercial and social available games to draw players in the long run, and not just in the context of tightly controlled research studies. Our next step would be to present an integrated solution, by making a repository of the games that could be called "pharmacy of games". Based to the patient's condition and their interests, physicians may “prescribe” combination of games for certain period of time. We also see multiplayer games to have a great potential to motivate patients to engage in an effective and fun rehabilitation process. Another aspect of our future work would be the implications of immersive head-mounted displayed games on both motivation and recovery of users, focusing on the fact that even watching someone performing a motion may increases the brain firing-ration required for the recovery.

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