Architecture guideline for game-based stroke rehabilitation

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Abstract

Purpose – Strokes are the most common cause of long-term disability of adults in developed countries. Continuous participation in rehabilitation can alleviate some of the consequences, and support recovery of stroke patients. However, physical rehabilitation requires commitment to tedious exercise routines over lengthy periods of time, which often cause patients to dropout of this form of therapy. In this context, game-based stroke rehabilitation has the potential to address two important barriers: accessibility of rehabilitation, and patient motivation. The paper aims to discuss these issues.
Design/methodology/approach – This paper provides a review of design efforts in human-computer interaction (HCI) and gaming research to support stroke rehabilitation.
Findings – Based on extensive review, this paper highlights challenges and opportunities in this area, and discusses an architecture guideline for a game-based stroke rehabilitation system.
Originality/value – This study was an original study.

Keywords Video games, Health games, Human-computer interaction, Stroke rehabilitation, System architecture

Paper type Conceptual paper

1. Introduction

Stroke, which is the sudden death of brain cells in a localized area due to inadequate blood flow, is one of the most common causes of long-term disability of adults in developed countries (Feigin *et al.*, 2003). The consequences of a stroke include visual, cognitive and motor skill losses where some patients may lose both memory and speech. As a result, up to 85 per cent of stroke patients suffer from hemiparesis – weakness on one side of the body – and between 55 and 75 per cent of survivors experience motor skill deficits. Conditions such as hemiplegia – paralysis or weakness on one side of the body including the loss of control over the legs – can result in a physical disability, which makes walking difficult or impossible. These issues often substantially limit an individual's ability to interact with the world, and reduce the level of independence (Bach-y-Rita *et al.*, 2002; Rehana, 2013). In this context, increased dependency on the care of others negatively influences the physical and emotional well-being of stroke survivors which negatively impacts the quality of life (Maclean *et al.*, 2002).

Fortunately, rehabilitation and continuous participation in occupational therapy can alleviate some of these consequences and support the recovery and independence of stroke patients. However, physical rehabilitation often requires commitment to tedious exercise routines over prolonged periods of time (Balaam *et al.*, 2011). Many stroke patients could recover some physical functioning by performing hundreds of daily repetitions of motions with affected limbs (Alankus *et al.*, 2010). Effective rehabilitation programmes that are initiated after stroke, and which can improve the recovery process and minimize functional disability (Duncan *et al.*, 2005), are expensive, labour intensive (Bach-y-Rita *et al.*, 2002), and unavailable in some remote areas. In addition to these barriers, patients who enrol in

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rehabilitation programmes often fail to complete therapy routines (Michielsen *et al.*, 2011), leading to high-dropout rates and a loss of potential benefits.

There are technologies that have the potential to address accessibility of rehabilitation and patient motivation issues (Bach-y-Rita *et al.*, 2002; Wood *et al.*, 2003). As such, computer-based stroke rehabilitation can be independently conduct in the patient's home while reducing treatment costs and increasing 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 accomplish previously tedious tasks (Alankus *et al.*, 2010).

This paper provides a summary of design efforts in human-computer interaction (HCI) and gaming research to support stroke rehabilitation. Existing cases in the field of game-based stroke rehabilitation (e.g. the development of motion-based video games that particularly address rehabilitation among stroke patients Burke *et al.*, 2009; Alankus *et al.*, 2010), were reviewed.

This paper discusses the effectiveness of design efforts in HCI and gaming research to support stroke rehabilitation by integrating findings from medical research, which consider the health outcomes of game-based stroke rehabilitation (Section 2). Based on these results, challenges and opportunities in game-based stroke rehabilitation programmes are deliberated (Section 3). Critical components that influence the effectiveness of telerehabilitation are identified, and a guideline for system architecture that would offer game-based rehabilitation to broad groups of stroke patients is discussed (Section 4).

According to patient motivation issues and medical record needs, a gamed-based rehabilitation system for post-stroke patients should be non-invasive, safe, attractive, and accessible at any time and any place (especially in the home), to record patient progress, and provide feedback for physicians as needed. Further exploration of design opportunities in the field of game-based stroke rehabilitation is an important step towards the creation of games that are accessible and motivational for stroke patients. If effectively managed by medical staff, games can be adapted into medical practice. They can provide and empowering experiences by contributing to patient recovery from strokes.

2. Literature review

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

Approach

In order to review existing literature in the field, keywords regarding stroke rehabilitation were collected from the Medical Subject Heading controlled vocabulary thesaurus. The collected keywords are: "Apoplexy", "Cerebral Stroke", "Cerebrovascular Accident", "Acute", "Rehabilitation", "Restoration", "Recovery", and "Game". From a total of 36 studies, published between 1997 and 2015, 32 were strongly related to this study. In this context, research in the area of stroke telerehabilitation systems suggests that maintaining patients' motivation is an important step towards ensuring therapy success. However, poorly designed and implemented technology-based rehabilitation would often lead to tedious and repetitive tasks, which may result in a significant reduction in patient's participation.

Motivation

Case studies have shown that games and similar interactive technologies have the potential to provide significant external motivation for stroke patients. Hence, the greater a patient's motivation to participate in rehabilitation tasks is, the more likely she will continue active participation. Similarly, longer therapeutic sessions could lead to greater functional outcomes over the course of treatment (Flores *et al.*, 2008). Therefore, home-based stroke rehabilitation games may help motivating stroke patients to perform the necessary exercises (Alankus *et al.*, 2010). By decreasing the monotony of repeated motions and providing performance feedback, these games are designed to help patients in recovering from a stroke. To have the maximum effect on patients' recovery, these games must ensure that patients correctly perform therapy motions and also provide a motivating context for therapy. It is also suggested that games may provide a sense of social connectedness with other stroke patients which could help decrease patients' sense of isolation and increase their motivation to exercise (Alankus *et al.*, 2010). As another example, Colombo *et al.* (2005) used a specific robot-aided rehabilitation system to create a simple game in which a patient tries to move a coloured circle from an initial position to a goal position using a robotic device designed for arm rehabilitation. Other research works have looked at the use of different input devices in rehabilitation games. For example; Broeren *et al.* (2008) used a pen-like haptic device to create several three-dimensional games.

In 1970s, Bach-y-Rita *et al.* (2002) adopted the newly introduced electronic pong games for the functional training for hemiparesis limb patients. Customizable input controllers were developed to match the varying grips of the stroke patients to be used with a modified exercise track. The second version of the game used an actuator/sensor sliding lever, where the lever was attached to a "trolley car" that rolls on ball-bearing wheels inside a wooden box.

Adaptation

One important question in the field of rehabilitation is whether efforts should be spent on adapting games that are developed for recreation, or to build games specifically for use in rehabilitation. To this end, some studies suggested partnerships between clinician-scientists with expertise in gaming and companies that produce consoles or companies that develop games to produce desirable games for rehabilitation (Deutsch *et al.*, 2011).

Alankus *et al.* (2010) reviewed games that were developed to assist stroke patients in earlier stages of recovery. They developed a series of games using various input devices. Their studies aimed to measure the effectiveness of different design approaches by having different goals and modes (such as single or multiplayer, cooperative or competitive). For example, they developed a series of games by using a haptic glove to improve the player's finger flexion and extension. As such, players could scare away butterflies, play the piano, and squeeze virtual pistons.

A study published by Jung *et al.* (2009) described interdisciplinary efforts involving researchers from the fields of communication, electrical engineering, computer science, psychology, and physical therapy, to develop three-dimensional game environments for post-stroke recovery. The study's main goal was to improve on everyday life activities that patients are unable to perform after a stroke. Then, the study explored the goals and patterns of movements in corresponding training tasks from traditional therapy. This was a critical step in order to transform these training tasks into digital 3D games. The study suggested that game interface is the crucial factor for determining the form and quality of interaction. It was also mentioned that the visual and audio feedback is another essential game features which could make digital games interesting, interactive, and exciting.

Saini *et al.* (2012) presented a list of game design principles for arm and leg rehabilitation with a standard angle based representation of the full body motion during exercise.

The goal of the study was to improve the accuracy of post-stroke exercises. The study showed several benefits of using off-the-shelf games hardware in stroke rehabilitation such as an increase in patients' motivation. The result showed an improvement in patients' memory and concentration, a better grasp of the game mechanics in a shorter amount of time and a decrease in the need for a technical expert or operator. The authors argued that utilizing off-the-shelf games hardware might improve the effectiveness of the rehabilitation process.

Borghese *et al.* (2013) described a game engine that has the characteristics needed to support rehabilitation at home. According to this study, games should be adapted to each patient's functional status, and monitoring the patient's motion is mandatory to avoid maladaptation. The authors argued that adaptation, monitoring, and real-time evaluation of the movements should be provided to the patient in real time.

In 2007, Goude *et al.* (2007) presented a model for a haptic and stereovision immersive workbench intended for daily use in stroke patients' homes. A customized virtual reality framework linked to a haptic workbench was used to prototype and implement training games based on different patterns. In all, 20 games were developed including games for upper extremity reaching exercises, neglect assessment, and coordination training activities. These variations of games provide a range of activities that can be used to personalize rehabilitation. This study presented a model for game design 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.

Home-based games

Researchers have also explored the possibility to design games to be used in patients' home. Taylor *et al.* (2009) introduced a game-based tool for rehabilitation of stroke patients in their home environment. The tool was the result of an exploratory development project in which researchers in the serious games area and experts in stroke rehabilitation collaborated to develop a motivating, easy to use and relatively inexpensive tool for relearning functions lost due to a stroke. The aim of the project was to develop a robust home-based rehabilitation system for regaining functions lost due to a stroke. The usage of the tool could be carefully monitored, which made it possible for health care personnel to supervise and assist patients. Sanchez *et al.* (2006) developed training exercises modelled on everyday tasks. Vogiatzaki *et al.* (2014) reported the results of a project where a game-based training system had been proposed allowing physicians to supervise rehabilitation of patients in their own homes. This approach enables patients and their caregivers to effectively apply rehabilitation protocols in their home settings, while leading physicians are able to supervise the progress of rehabilitation (and provide guidance if needed). The proposed system architecture includes a patient system deployed at home, supporting physiological remote monitoring of patient well-being. The system also runs the rehabilitation games and offers full integration with online data repository for sharing information between the patients and their physician(s).

Virtual reality cases

A Kinect-based system by Chang *et al.* (2011) used as a rehabilitation tool for children with acquired muscle atrophy and cerebral palsy. In other similar efforts, Todorov *et al.* (1997) used a virtual reality system for two-player table-tennis training. Patients with hemiplegia were trained in a virtual setting. One of the participants showed clinical and functional motor skill improvements and the second showed no improvements. Yeh *et al.* (2005) developed a series of 3D games involving manipulating objects. Shin *et al.* (2014) developed a virtual reality system for enhancing upper extremity function in stroke patients. The study presented by Hijmans *et al.* (2010) aimed to determine the effectiveness of a bilateral, self-supported, upper limb rehabilitation intervention by using a movement-based game for chronic stroke patients. Their assessment for upper limb section was used as the primary outcome. Although all games required large cursor movements in both the horizontal and vertical direction, the study showed that when computer assisted, bilateral upper limb rehabilitation using a low-cost game controller can significantly improve upper limb function over a short duration in adults with chronic strokes. Burke *et al.* (2009) built two webcam colour tracked games similar to Whack-A-Mole. Ustinova *et al.* (2011) made a 3D videogame to enhance arm postural coordination in traumatic brain injury patients. In 2014, Shin *et al.* (2014) developed a task-specific interactive game-based virtual reality system for post-stroke rehabilitation of the upper extremities, and assessed its usability and clinical efficacy. Therapists specialising in stroke rehabilitation consulted in the design of activities included in the game. These activities were intended to promote incremental improvement in range of motion and endurance, strength, and deviation from synergistic motion patterns.

Based on this review of existing design efforts in the field of game design for stroke rehabilitation (see Table I), this paper discusses opportunities in game-based stroke rehabilitation

Rehabilitation body area	Input device and relevant research article(s)
Balance and mobility	Motion controller (Deutsch *et al.*, 2011)
Cognitive and motor skills	2D input device (Alankus *et al.*, 2010), accurate 2D input device (Alankus *et al.*, 2010), accurate horizontal 1D input device (Alankus *et al.*, 2010), basic 1D input (Alankus *et al.*, 2010), basic vertical 1D input (Alankus *et al.*, 2010), vertical 1D inputs (Alankus *et al.*, 2010)
Finger	3D environment (Jung *et al.*, 2009), (Merians *et al.*, 2002), mobile tablet (Carabeo *et al.*, 2014)
Gait ability	Game console and camera (Shin *et al.*, 2010)
Hand	Forced feedback glove (Jack *et al.*, 2001), hand tracking device (virtual reality) (Souza *et al.*, 2012)
Pronation and supination	3D environment (Jung *et al.*, 2009)
Hand and leg	Virtual reality camera (Saini *et al.*, 2012)
Motor skills	EMG signals and robot (Shusong and Xia, 2010), virtual reality camera (Borghese *et al.*, 2013), (Chang *et al.*, 2011), electromagnetic sensor (Todorov *et al.*, 1997), pen-like haptic device (Broeren *et al.*, 2014), virtual reality, haptics and, modern sensing technique (Yeh *et al.*, 2005)
Thumb and finger (range of movement)	Forced feedback glove (Merians *et al.*, 2002)
Upper arm motor	Virtual reality camera (Maung *et al.*, 2014)
Upper limb/extremity	3D awareness sensor (Shin *et al.*, 2013), actuator/sensor sliding lever (Bach-y-Rita *et al.*, 2002), game console (Taylor *et al.*, 2009), joystick (Bach-y-Rita *et al.*, 2002), passive antigravity arm orthosis (Sanchez *et al.*, 2006), virtual reality (Shin *et al.*, 2014), 3D motion controller (Hijmans *et al.*, 2010), robotic exoskeleton arms (Simkins *et al.*, 2012), handheld roller-ball device and webcam (De Leon *et al.*, 2014), virtual reality camera (Norouzi-Gheidari *et al.*, 2013), virtual reality camera and motion sensor (Vogiatzaki *et al.*, 2014), handheld device (Wood *et al.*, 2003), webcam (Burke *et al.*, 2009), motion controller (Lee and Tien, 2012)
Wrist muscle activation	Surface electromyography (sEMG) (Brown *et al.*, 2014)
Upper limb/extremity and gait ability	Virtual reality camera (Maung *et al.*, 2014)
Arm	3D environment (Ustinova *et al.*, 2011), wrist motion controller device (Schuck *et al.*, 2011)
Coordinated arm and shoulder movement	3D environment (Jung *et al.*, 2009)

Table I.
Summary of devices and interfaces for stroke rehabilitation

(see Section 3), suggests an architecture guideline for a game-based stroke rehabilitation system (see Section 4) and highlights the most important benefits of such a system. These are important steps to tie together previously fragmented areas of research, and in order to identify game design opportunities that are associated with the social and medical aspects of stroke rehabilitation.

3. Rehabilitation game design opportunities

Benefits of game-based stroke rehabilitation

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

Increased patient motivation and engagement. Previous work in the field of game-based stroke rehabilitation emphasized the motivational power of games to increase patient commitment to follow through with therapy routines. Studies have demonstrated the effectiveness of games in this respect, showing that systems which focussed on factors such as entertainment are able to achieve increased engagement (Bach-y-Rita *et al.*, 2002; Wood *et al.*, 2003; Alankus *et al.*, 2010; Saposnik *et al.*, 2010). For example, Bach-y-Rita *et al.* (2002) presented a system which utilizes the context of a digital game to efficiently entertaining users. Such entertaining systems may help users to be more focussed on the goals in games, rather than the repetitive rehabilitation exercises, potentially achieving better progress in their recovery.

The required movements in stroke rehabilitation for the recovery of usage of affected limbs involve a high amount of repetition, which can quickly become a boring and uninteresting activity for patients (Balaam *et al.*, 2011). However, concern around increasing patient motivation to perform these exercises has not received enough attention (Bach-y-Rita *et al.*, 2002). One reason might be the great diversity of stroke types and related symptoms, which makes it difficult to design a single system that can effectively provide engaging tasks for a variety of users.

Decreasing access barriers for rehabilitation

As mentioned earlier, another concern related to stroke rehabilitation is the fact it demands time and equipment. Depending on the severity of patient's condition, the recovery process can take from weeks to years of constant daily practice of hundreds of exercises. As a result, the treatment goes beyond rehabilitation centres, and patient engagement with in-home exercises remains a crucial success factor (Balaam *et al.*, 2011). 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 exercises in the recommended way (Alankus *et al.*, 2010). Keeping this in mind, it is important to find a solution that is not only reasonable for rehabilitation centres, but also affordable for most common residences. With the advancement of digital technology, there are more opportunities for cost-efficient interactive applications (such as video games) to be used as supporting tools in rehabilitation. They are, however, required to be adapted in order to fulfil the needs of the rehabilitation plan (Flores *et al.*, 2008).

Design opportunities in game-based stroke rehabilitation

Patient independence and multiplayer. The vast majority of patients affected by stroke eventually become severely dependent on family members or friends. Due to decreased efficiency of their motor skills, cognitive and visual problems, few patients can return to full-time work, or perform common activities of daily living (Alankus *et al.*, 2010). Therefore, it is important to consider a patient's independence when designing rehabilitation systems. This includes empowering users to feel in control when using a game-based rehabilitation programme. For example, games with multiplayer functionalities may offer a cooperative or competitive setup that can be used by families, friends or even other patients (Alankus *et al.*, 2010; Balaam *et al.*, 2011). However, it is important for the game to provide a possibility for individual use, thus respecting patients' independence for not being reliant on others to interact with the rehabilitation programme. 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, whereas a competitive scenario, where they may feel inferior, and deem the competition unfair.

Customization and adaptability. Due to the diversity of affected limbs and the variance in severity of strokes, 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, focussing on the needs of each individual patient (Alankus *et al.*, 2010). Moreover, it is important for the game to offer some adaptability functions that can be fully automatic or manual. As the patient's training progresses, their 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 of vital importance for patient progress to recovery and preservation of their interest in the game (Flores *et al.*, 2008; Alankus *et al.*, 2010).

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 (2012), a simple use of a visual system highlighting areas of the body that are showing improvements due to the performed activity may increase 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 of the benefits or not noticing progress (Maclean *et al.*, 2002). Early introduction of relevant information prior to playing shows that the rehabilitation objectives of each exercise could help avoid discouragement (due to the lack of information) and provides greater ease when creating new personal goals.

Diversity and flexibility of gaming environment. Patients affected by strokes are a heterogeneous target audience, hence there is also a challenge when making design decisions while designing a single rehabilitation system that uses entertainment as one of the key pieces to provide user engagement (Balaam *et al.*, 2011). 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 offered to each user, in turn preventing boredom with a single game. The topic of content diversity was also observed in a study in which a rehabilitation system of a book reader was efficient at the beginning, but as it contained as just a single book it failed to engage users over a longer period of time (Balaam *et al.*, 2011).

Rehabilitation exercises. Rehabilitation systems need to be designed in a way to perceive the precision and accuracy of user performance when performing the necessary gestures. The help of a physiotherapist is necessary together with the development team to effectively design the right motions and mechanics. The system must accurately track users' gestures and preventing incorrect or inadequate performances (Alankus *et al.*, 2010). 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 (Jack *et al.*, 2001).

Generally, these opportunities highlight the complexity of development challenges involved in the creation of game-based solutions for stroke rehabilitation. To this end, the next section discusses a guideline for a game-based stroke rehabilitation system architecture which can serves as a starting point for developers wishing to design systems for game-based in-home stroke rehabilitation to offer empowering and effective patient solutions while maintaining communication channels with medical professionals.

4. Guideline for system architecture

A rehabilitation system should meet a number of basic requirements to ensure it is beneficial for both patients and health care providers. Some of these benefits identified from previous work include:

- ability to create and modify customized rehabilitation programmes based on patients medical needs and their access to input devices;
- delivery an engaging suite of rehabilitation tools to keep patients interested in following a prescribed rehabilitation path;
- ability to be used at any time and any place, especially in the comfort zone of the patient – this also includes working with devices which patients already own and is familiar with rather than introducing therapy-specific hardware;
- being non-invasive and protect the privacy of patients;
- ability to record the progress of patients as they use various prescribed rehabilitation games; and
- providing physicians with access to their patients data in order to monitor patients progress and update their rehabilitation regime.

These requirements introduce a level of complexity that supersedes those in traditional serious game development due to the fact that they require the application to remotely feedback to the medical practitioner depending on the user performance. To accommodate these requirements, a game architecture guideline that can used to design a rehabilitation programme for stroke patients is discussed here. Figure 1 shows four element of the architecture guideline for such system, which is proposed based on collaboration with an eHealth consultant.

The architecture guideline has the following main components:

- Game selector engine (GSE): the GSE is used by the physician to develop a rehabilitation programme for new patients, and to update the rehabilitation programme for patients who are already enroled in the system. The GSE allows the physician, to select games and their parameters that can best help each individual patient with rehabilitation, based on the stroke affected body area and the various game devices available to the patient.

  Table I shows a database of compiled information of references for existing stroke rehabilitation games that can be used for various body parts, and the corresponding required input sensor.
- Patient gaming profile (PGP): the PGP records all the information pertaining to the patient, including their identity information, the rehabilitation programme designed by their physician, as well as any information related to their rehabilitation progress. This information includes configuration data for each of the rehabilitation tools prescribed to the patient by the physician.

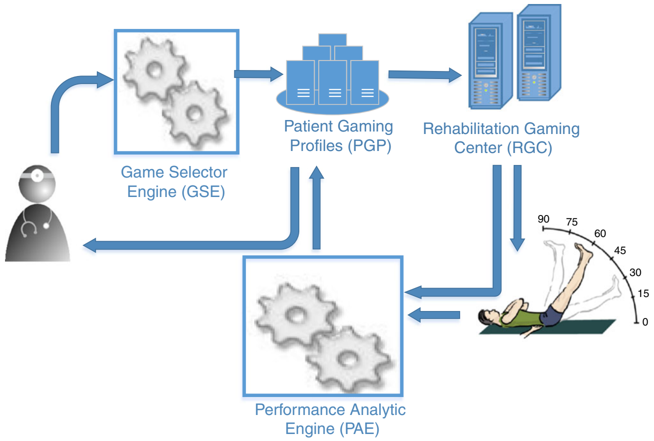

Figure 1.
Four elements of the architecture guideline

- Rehabilitation gaming centre (RGC): the objective of the RGC is to provide an environment where the patients can play the games that were prescribed to them by the physician. Each of these rehabilitation games is configured using the patient's profile.
- Performance analytic engine (PAE): the PAE is responsible for collecting data from each game played by the patient and for performing some analytics on this data. The objective of the analytics is to evaluate the progress of the patient with the rehabilitation programme. While most current games show only coarse data (in the form of a level or points), it is more useful to have games generate fine grain data which can be used to assess the progress of the patient on rehabilitating the targeted body area. The results of the PAE are stored in the patient profile for further evaluation by the physician. The GSE can also access the patient performance data, stored in the patient profile, to evaluate the progress of the patient.

5. Conclusion and future work

This paper provided a summary of game-based approaches to support stroke rehabilitation from the game design perspective. From reviewing both studies and implemented stroke rehabilitation games, it was shown that a combination of mental supports, self- and external-motivation, and accessible interfaces are important considerations for designing game-based rehabilitation. It is important to emphasize that playing games at home can be done anytime and can potentially empower patients to take ownership over their therapy. One potential development could be to leverage motivational pull of the commercial and social games available to attract players in the long run, and not just in the context of tightly controlled research studies.

In addition to reviewing current literature in game-based stroke rehabilitation, this paper makes two important contributions to the field: to identify and categorize opportunities for game-based rehabilitation games; and to discuss four critical elements that can serve architecture guidelines for designing such game-based stroke rehabilitation systems.

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