Developing customised Serious Games for Parkinson's Disease rehabilitation with the use of bespoke game sensors: Design Guidelines

Ioannis Theoklitos Paraskevopoulos[1], Emmanuel Tsekleves[2], Cathy Craig[3], Caroline Whyatt[3], John Cosmas[4]

[1]Faculty of Science and Technology, Anglia Ruskin University, United Kingdom

[2]ImaginationLancaster, Lancaster University, United Kingdom

[3]Movement and Innovation Lab, Queen's University Belfast, United Kingdom

[4] School of Engineering and Design, Brunel University, United Kingdom

Abstract

The research presented in this paper proposes a set of design guidelines and a Parkinson's Disease (PD) rehabilitation design framework for the development of Serious Games for the physical therapy of people with PD. The game design guidelines provided in the paper are informed by the study of the literature review and lessons learned from the pilot testing of serious games designed to suit the requirements of Parkinson's Disease rehabilitation protocol. The proposed PD rehabilitation design framework employed for the games pilot testing utilises a low-cost, customized and off-the-shelf motion capture system (employing commercial game controllers) developed to cater for the unique requirement of the physical therapy of people with PD. Although design guidelines have been proposed before for the design of serious games in health, this is the first paper to propose guidelines for the design of serious games specifically for PD motor rehabilitation.

Keywords— Parkinson's; rehabilitation; physiotherapy; wiimote; exergames; serious games; virtual reality; design guidelines; customised; difficulty; adjustment; calibration

INTRODUCTION

PARKINSON'S disease (PD) is a slowly progressing neurodegenerative brain disorder, characterised by a reduction of neurones within the substantia nigra, the brain area responsible for the dopamine production. This reduction of dopamine production is thought to result in the range of debilitating motor and non-motor symptoms associated with PD.

It is estimated that 6.3 million people suffer from PD worldwide [1] , with no discrimination to race or cultural background. Statistics indicate that there are approximately 1 million people in the USA diagnosed with PD [2], and over 1.2 million in Europe [3]. According to HESonline [4] and Parkinson's UK [5], there are approximately 120,000 people living with PD in the UK alone. The age group mostly affected by PD is between 60-79 years [5], nevertheless there are cases of PD in the age range of 20-39; the "the young outset" of PD. There are four key motor symptoms associated with PD, namely Tremor, postural instability, rigidity and Bradykinesia [6].

Although research into finding a cure is on going, there is currently no comprehensive or radical treatment for PD, however, there are a series of drugs that are widely used to support the management of the symptoms. Depending on the severity of symptoms there are also a series of surgical options available. Apart from drug-based solutions, there is a wide range of therapies available for patients to deal with everyday tasks and activities. According to Parkinson's UK [5] therapists provide PD patients with a series of options that include but are not restricted to courses of occupational therapy (ref), physiotherapy (ref), diet plans (ref), and speech and language therapies. Complimentary therapies such as acupuncture, massage therapy and aromatherapy are also fairly popular among people with PD [7].

Physical rehabilitation is a common treatment and disease management tool often prescribed by clinicians, especially in recent years. The prescribed exercises often target particular motor? Symptoms such as …, with beneficial results. Tomlinson et al.[8], present an extensive review of physiotherapy treatments and their assessment of effectiveness., and conclude…. Along the same lines, the review of Goodwin et al. [9] examined the effects of physiotherapy for PD and found evidence of physiotherapy being very beneficial to aspects of the patient's life like physical functioning and well-being. Moreover, Nimwegen et al. [10] studied levels of physical inactivity associated with PD, by quantifying and comparing levels of everyday activity in individuals with PD and a control group (were these age matched??). As expected the levels of PD patients were lower than the control group. However, this variance was not completely justified by the motor impairments, suggesting other reasons behind inactivity, such as poor engagement to physiotherapy programmes and low levels of patient enjoyment. Finally, a study by Farley & Koshland [11] [12] show(s) evidence that the training of movements requiring both speed and amplitude can reduce the symptoms such as bradykinesia and hypokinesia. This rehabilitation intervention, which is referred to as Training BIG (ref), applies the principles of established and effective treatments for speech rehabilitation in PD, such as the Lee Silverman Voice Treatment (LVST)[13], to the motor system.

This paper will provide an overview of the available literature (in which area?), identify the key challenges and opportunities, and propose a design framework to address these limitations. This is followed by a description of the pilot games prototype designs. The administration and testing of the pilot games is illustrated in section 4.1, with the results presented in section 5. The next section (section 6) presents the derived design guidelines from the preceding discussion. Finally, the conclusion summarises all the work presented in this paper.

1 LITERATURE REVIEW

1.1 PD Diagnosis and Symptoms Management

The most common rating scale used by medical professionals to assess a patient with PD is the Unified Parkinson's Disease Rating Scale (UPDRS) [14]. The patient's condition is stratified in four categories namely: Mentation, Behaviour and Mood; Activities of Daily living; Motor Examination and Complications of Therapy [15]. A total of 42 features are examined, to assess the severity of the condition of each patient on a 0-4 scale with the lower limit representing no physical or cognitive impairment, and the upper representing severe disability. This type of assessment is imprecise and inconsistent as it relies on the subjective descriptions of the patient for their own condition. Each assessment may be distal to the next and therefore there is the necessity of the patient recalling the previous condition or even being able to describe the variance of the symptoms occurring in a smaller timeframe. Furthermore, the UPDRS assessment necessitates a visit to the clinic and thus, possibly exposing the patient to further discomfort especially those at the more progressive stages of PD.

Motor symptoms of PD can affect an individual in a variety of ways. For example, Bradykinesia, for example, can result in very poor performance of movements that require speed. The literature has revealed several compensatory mechanisms to help overcome such issues (refs). These mechanisms are embodied in visual and auditory cues that help the patient improve the motor impairment caused by the symptoms of PD. The literature indicates that external audio and visual temporal cues can be used by participants to guide and control actions, thus aid the performance of tasks [16]. Auditory cues in the form of rhythmic auditory simulation (RAS) have been studied by McIntosh et al. [17]. The results indicated a significant improvement in gait velocity, cadence and stride length with faster RAS. A more recent study [18] examined the effects of RAS on gait and finger tapping and shown improvement on both those rhythmic types of movement. Visual cues have been investigated in a series of studies as [19-21], with all of them indicating that visual cues aid the movement by guiding the patient and refining movement patterns.

2.2 Serious Games as Rehabilitation Strategy for PD

The utilisation of Serious Games (SGs) for motor rehabilitation have been widely investigated and a number of research studies examine the use of video games and VR for the rehabilitation of motor impaired individuals suffering from a broad range of diseases. According to the review of Holden [22], VR training appears to have a range of advantages over conventional physical rehabilitation. The same review summarises the studies conducted in the use of VR for motor rehabilitation in the following points. Firstly, it is established by the reviewed literature that people with disabilities in fact appear able to acquire motor skills within virtual environments (Refs from review). Moving on, the motor tasks performed in the virtual world can be transferred to the real world in most cases (refs and what cases?). In addition, VR has been found to result in stronger? benefits to motor skills than real-world physiotherapy. Furthermore, there was no reporting of negative symptoms (i.e. cyber-sickness) by the participants in any of the reviewed studies.

The potential of VR as rehabilitation tool for elderly adults with cognitive disorders such as PD, stroke or Alzheimer's disease was examined by Cherniack [23]. The study enumerates the application types of VR and reviews the available literature on each of them to conclude that VR-based rehabilitation frameworks for such diseases can offer a more comprehensive, flexible and safer environment that will increase the engagement of the subjects with the interventions. More specifically, in the context of PD, the effectiveness of customised SGs and commercial off-the-shelf (COTS) game sensors has been considered. Sensors such as the Nintendo Wiimote, Microsoft's Kinect, Sony Playstation Eye, and even simple webcams, are among the COTS most employed in the available literature [33-40]. Among those sensors and game platforms, the Nintendo Wii is the one that has been predominately used, due to the popularity of it Wii Fit title in rehabilitation studies. A study by Sugumaran & Prakash [24] suggests that there is a connection between simply playing games and dopamine release, as the latter occurs with every kind of physical exercise. Another research report [25] indicates that apart from dopamine release, physical activity is shown to improve the wellbeing of patients on activities of daily living (which activities?). The portability of the Wii console is a further advantage in its role as a rehabilitation platform, allowing therapy sessions to occur in a safe and comfortable environment (e.g. patient's home). Furthermore, as stated in [26] and [27], the use of the Wii promotes the motivation, especially of the elderly, as well as participation in physical activities and social interaction.

A more advanced clinical trial, such as [28], has shown that PD patients using Wii Fit for certain periods of time (how long) improved significantly in UPDRS-section 2, which refers to the Daily Living Activities outcome measure Moreover, a case study by Zettergren et al [29], demonstrated improvement in gait speed, balance, functional mobility, as well as cognitive aspects, such as depression (in all measured pre-test and post-test using clinical assessment scales for each aspect) following game training using the Wii The aforementioned studies, although promising, do not form robust evidence on the effectiveness of games interventions into PD rehabilitation. Indeed, a recent systematic review of the evidence for exergames for PD by Barry et al. [30] , states that exergaming for PD has been proven feasible but in order to assess its effectiveness larger scale, clinical trials should be conducted.

2.3 Customised Interventions for PD rehabilitation

Commercially available games and peripherals like the Nintendo Balance board, Wiimotes and Microsoft Kinect, have been widely used for the assessment and rehabilitation of motor dysfunctions for PD patients and have been found to improve the participants' well-being as seen in some of the aforementioned studies [33-40]. Nevertheless, the use of off-the-shelf games has been shown to be limited or completely inapplicable when it comes to patients with severe conditions [31]. Specifically, the commercial games may be too difficult for the patient to play with and thus induce frustration and reduce motivation. Furthermore the therapist has no control on the range of movement that is required by each patient, thus limiting the utility and usefulness of such interventions for the purposes of a rehabilitation session. Therefore, from a therapist's perspective [32], off-the-shelf games lack the feedback required to track performance, and prevent full customisation of the exercises to match the individual participant's requirements.

A specific example of such a case for PD is presented in [31] . In this study, the specific symptoms of were taken into account, and combined with common methods of rehabilitation for PD. The multimedia system developed consisted of an infrared web-camera (acting as a motion sensor) and instructed physiotherapy exercises assisted by audio and visual cues. Moreover, customised design principles for PDR games were outlined by xxxx [33]. Similar to [31], the authors proposed the combination of "Training Big" with visual and auditory cues; the most effective physiotherapy and perception support mechanisms for PD. The system presented in [33] consisted of a Sony Playstation Eye camera, a marker-based webcam using a motion capture approach and a set of mini-games customised according to the PD rehabilitation protocol. Using a similar web-camera motion tracking system xxx [34], suggest using video-based analysis of real-time performance of physical exercises. While [35], demonstrate the benefit of synchronised music beats (audio feedback thus cues) to aid a participants movement when training motor skills in a gaming context using the Microsoft Kinect. The potential of the Microsoft Kinect as a support therapy has been further highlighted [36-37], with authors also demonstrating the potential of using colour based tracking algorithms [36] to support customised games.

A larger scale, real-time rehabilitation system was proposed by [38]. This approach involves multiple infrared mocap cameras, a wall projector and visual and audio controllers for the audio-visual cues. The design of such system follows the principles set by prior studies as: usability in clinical area (refs), "training BIG" protocol (refs), accuracy of motion capturing and measurements (refs), repetitive and variable nature of exercises (refs), engaging and motivational and performance adaptable (refs). This approach is a robust and precise solution to PD rehabilitation. It nevertheless suffers from portability issues, as there is the requirement of a dedicated space for the system to be installed restricting the options only to clinical-based and not home-based solutions.

Finally, Su et al. [39] propose another solution to increase the movement range of the upper limb of PD patients. This study suggests the use of a VR projection-based system, coupled with an affordable and precise motion capture system (Patriot by Polhemus Inc.) utilising electromagnetic field motion capturing, and a Wii Balance board. The use of polarised glasses supported immersion to improve the VR experience and a customised game was employed (catching virtual targets). The effects of speed of VR ball catching were examined and found to be related to the speed of the upper limbs of the patient. The manipulation of the speed by the therapist is suggested to be beneficial for the PD patients.

2.3 Design Guidelines

When designing games for rehabilitation, it is very important to keep in mind the variations in patient ability, both cognitive and motor. Not all exergames or cognitive tasks training platforms are suitable for the scope of PD rehabilitation, which is generally the case for all cohorts of patients and all types of diseases and disabilities. A study by dos Santos Mendes et al. [40] confirmed the hypothesis that PD patients would show deficits in comparison to healthy elderly depending on the requirements of the game. Among the ten WiiFit games tested for the purposes of this study, PD patients had normal learning and retention compared to the control group of the elderly in seven of them but had lower performance on five. Furthermore and after some training, PD patients still could not improve in three of the games tested, whereas the control group showed improvement. These results indicate the importance of tailoring and customisating games to align with the requirements of the targeted group. Moreover, the lack of literature on evaluated guidelines for PD SGs further endorses the need for such guidelines to facilitate adaptation and personalisation. As stated in [41] , the main issue existing in SGs in sports and health, is the lack of personalisation and the strong need of engagement for sustainable use. The need of adaptation and calibration is also examined by Geurts et al. [42] where the authors present four SGs tailored for patients with spasticity and motor degeneration. Their study derived to a series of results which are translated into game design requirements and guidelines. The authors point out the huge disparity among the motor skills of the patients, therefore, automatic calibration and dynamic adaptability within the game was an important aspect of the design. The same issue is raised in the study of Palacio et al. [43] where the authors present design guidelines for videogames to promote leisure activities for older adults. This study indicates a gap in the gaming industry. Namely that all of the games developed focus on younger populations and accordingly the game designs are tailored for a younger demographic, excluding older adults. The same study provides a number of design guidelines, which include the use of big letters and buttons to accommodate easier interaction for the elderly and the absence of skill evaluation to reduce player frustration in case the game objectives cannot be achieved. The influence of non-reward gameplay has been studied in [44]. The brain activation associated by non-reward games is hypothesised to examine the influence in motor ability and executive function in PD patients and showed positive outcomes. In particular, winners displayed improved memory and motor skills. Another research article that investigated the development of design guidelines for SGs in rehabilitation is [45]. The authors developed a set of guidelines for developing SGs for Alzheimer patients. The main four aspects of the design were the appropriate choice of challenges within the game, the design of suitable interactions for the cognitively impaired, adoptability and dynamic calibration of difficulty levels, and effective design of visual and auditory cues for the aid of cognitive training. The same points, individually or in groups, are found as design guidelines in studies that focus on PD motor rehabilitation.

The key design elements for VR games for movement rehabilitation are summarised in the review of Lewis & Rosie [46]. The review outlines studies that have developed SGs for rehabilitation in a user centric manner, and identify a set of key design suggestions and themes; the sense of control by the player, the feedback in terms of score and success, experience, and the element of adoptability to constantly challenge the player to reach their maximum capabilities, are among the most dominant themes. The authors mention that although their review is restricted to SGs for stroke and cerebral palsy it is high likely that the principles will be fit to other cases (e.g. PD) and recommend the further investigation of user-requirements' capture to facilitate the maximum effectiveness and engagement with SGs for rehabilitation.

2.4 Summary of related work: challenges and opportunities

The related work presented above outlines the features and practises of game design for PD rehabilitation interventions, as well as general design guidelines for SGs for rehabilitation. The features of the games and design guidelines presented above can be summarised, to the following requirements when designing games for PD:

- *Accuracy:* The motion capture system, utilised for the purposes of a study as this, should be very accurate as the biofeedback is to be analysed to evaluate the performance and progress of the patient.
- *Home-based solution:* The gaming sensors that are to be employed for the motion capture need to be commercially available and of low-cost.
- *Real-time biofeedback:* The rehabilitation platform should realise the potential of real-time biofeedback to the clinician through a dedicated clinician platform.
- *Customised Games:* The designed games should enable visual and auditory cues, and adjustable level of difficulty that can monitored remotely by the clinician. The genre of these games is also referred to by the term "exergames" which is a portmanteau of exercise and game.
- *PD Rehabilitation Protocol:* The designed games should be a translation of Training BIG exercises into VR games. The proposed system must be very flexible so that the translation of any exercise into a mini-game to be very easy to accomplish.
- *Automated system Calibration:* The system should incorporate an automatic or semi-automatic calibration system that will match the range of movement of the patient with the range of movement required by the virtual game player.
- *Feedback/reward system:* A motivating and encouraging feedback system increases entertainment and thus the engagement and involvement of the player with the game and reduces the risk of abandonment of the game and physiotherapeutic treatment.

Therefore, taking into account all key features found in the literature up-to-date, as well as the lessons learnt from experience with users and pilot testing of the designed games, will form a broader design approach, which incorporates all the above design requirements and guidelines. These design guidelines foster new knowledge of key features of game mechanics and gameplay in order to maximise the engagement of the patient with the rehabilitation interventions. The game design is patient-led as the patients are actively involved in the design and their feedback is leading the design. In addition, the design initiates from the physiotherapy and also facilitates high level of adaptability. The user study for evaluating the proposed design framework is also presented.

3 PD MOTOR REHABILITATION DESIGN FRAMEWORK

The discussion above presents potential application for home-based rehabilitation strategies that utilise commercially available gaming sensors like the Nintendo Wii and bespoke computer games. The summary of the scattered guideline elements found in the literature, as well as novel approaches for SGs for PD, has informed the formulation of a design framework. The PD rehabilitation design framework, depicted below in Figure 1, consists of three layers. The first layer is a motion capture system, in our case utilising the Nintendo Wiimote. This layer's output is in the form of quaternion (hyper-complex numbers widely used in calculations of three-dimensional rotations), therefore the sensor can be of any type given that it can output a quaternion motion data form. This way the proposed framework is sensor independent. However, for the purposes of our study and for the reasons of accuracy and following the technology limitations discussed in [46], we are using the Wiimote. The second layer consists of the custom video games corresponding to the rehabilitation targets and requirements. Within this layer the mapping of the motion data on the VR props (e.g. game elements, such as paddles in our rowing game) takes place, as well as the calibration, automatic difficulty adjustment and feedback to the player. The third layer is the VR instructor platform that aims at facilitating the clinician with live biofeedback and the possibility for level of difficulty adjustment. Figure 1 illustrates the schematic diagram of the layers of the proposed framework along with their interactions and the sections below describe them in more depth.

Fig. 1. Schematic diagram of the system architecture

The design features of accuracy, adaptability and calibration are covered in this system architecture level by providing the appropriate hardware infrastructure. The remaining design elements will be covered within the game environment through the appropriate design framework.

3.1 Motion Capture System

The motion capture system employed for the purpose of this research comprises of an off-the-shelf gaming sensor, i.e. the Nintendo Wiimote, and a bespoke communication interface between the Wiimotes (up to two) and local computers via Bluetooth and remote via the Internet. The motion data received by the terminals undergo a process of smoothing and multiplexing using a data fusion algorithm in order to achieve higher accuracy and precision. The end results are mapped into quaternion forms that translate the orientation of a constructed 3D body model and also are free from gimbal-lock. The angular rate measurements captured by the gyroscope sensor can be used to distinguish true linear motion from the accelerometer readings. The gyroscope is not free from noise, but since the measured rotation is less sensitive to linear mechanical movements and without amplifying hand jitter, both of which accelerometers suffers from, it allows capturing more complex orientation with a relatively better estimate than we would obtain by using accelerometers alone. A sensible approach for maximising efficiency is to average or concatenate the data that comes from the accelerometer and gyroscope by using a data fusion algorithm and simultaneously, we have employing a smoothing algorithm to remove any excessive noise from the signals, while still retaining the useful information. Filtering out and removing as much random noise as possible from the sensors' output raw information whilst retaining quality data is of fundamental importance [47],[48]. The Wiimote sensors are very responsive, but they cannot respond to the linear movement accelerometers specialise in. Yet, as described in the above section, when a gyroscope and an accelerometer are combined, the pairing of sensors facilitates a highly accurate one-to-one representation of the control device in 3D space. The quaternion data is forwarded locally or online and thusly can manipulate a virtual 3D object on the local computer (exergame) or provide the biofeedback to the clinician's party (remote terminal).

3.2 Automatic Calibration and difficulty adjustment system

As stated in the related work section above, the range of movement (ROM) of each patient differs significantly. Moreover, this range has to match the ROM of the game prop, whether that is a virtual avatar or just a game object as a boat oar. Patients with very restricted ROM have to be available to perform wide ROM in a game so they are not discouraged by failure. Hence, a calibration algorithm has to be employed to resolve this issue by registering the maximum ROM and matching it with the desirable ROM in the virtual environment. This calibration can be either performed before the game starts or during game play to dynamically adjust the ROM of the player. The dynamic adjustment of the ROM is a critical factor as a number of individuals display extended movement following initial phases of ‘warm up’ or in accordance to the game level and excitement. If the maximum ROM is recorded and sent online to the clinician platform, then it is very easy for them to adjust the desired ROM of the virtual player and therefore adjust the difficulty of the game. This can be implemented by an impact factor set by the clinician so that for example every 10^{o} of actual rotation of the patient’s limb, the virtual object registers only a fracture of that in the game. This way the clinician can adjust the difficulty on demand and according to the specific requirements of each player.

Moreover, we propose an automatic ROM calibration that can be overridden by the clinician should they wish to further challenge their participant/patient for better results. The automatic calibration does not require any prior performing of the game movement from the patient. The principle is that while the patient performs a repetition of the exercise, the system records the ROM by the corresponding minimum and maximum values of each axis of movement. Then, it is easy to calculate the ROM and adapt it with further formulas to the desired ROM of the game prop. An advantage of this approach is that the ROM is dynamically calculated and the mapping of the movement to the virtual environment dynamically adjusted. This way the improvement of the patient’s motion will result to a higher difficulty level and thus motivation to reach further. All of the above can be manipulated live by the clinician as previously described.

4 PILOT GAMES

The system architecture presented above facilitates accuracy and calibration of the system. The design of such games is challenging in its own nature, as the requirements of the players are often complex and diverse. Furthermore, the designer has to foster performance of PD physiotherapy and align with the targets of the physical rehabilitation to optimise the outputs of the physiotherapy. Hence, the design of the game has to allocate movement and agility that will coordinate physical exercises and not random repetitive movements in the sake of keeping active. Therefore, our approach proposes the translation of the physical rehabilitation regime to game concepts, where that is applicable. Therefore, we build upon the framework of suggested rehabilitation regime’s for PD from PD Society of UK [49], and designing game concepts for each of the individual exercise. Despite challenging, this ensures actions that successfully mirror physiotherapy techniques rather than random repetitive movements. In addition, the successful design elements mentioned in section 2.3 were incorporated. The application of the design principles mentioned above, guided the design and development of two pilot games. Two exercises were chosen from Keeping Moving [49], a guide for exercise and Parkinson’s Disease by PD Society of UK, and the author’s conceived two ideas to translate the said exercises into gameplay.

The Rowing game: The game aim is for the player to control a two-paddled row boat (bilateral movement) with the challenge of reach a specific point at a given time. The targeted exercise is shown in Figure 2.

Fig. 2. "Arm Reaching" Exercise [49]

The game mechanics focused on improving the users' speed, range of bi-lateral movement and reducing rigidity. The game was designed to collect specific biofeedback (measured in the game and displayed in the Clinician Platform), such as the range of movement of upper limbs in Euler degrees, speed in m/s2, spontaneity of movement etc. The game was designed to enable the user to use both arms simultaneously, in a reaching style exercise from a seated position. Visual cues appeared on the screen to direct player's movement. Audio was used to set the rowing tempo. The figures (figures 3,4) below illustrate the first and second version of the rowing game.

Fig. 3. Rowing game v1.0

Fig. 4. Rowing game v2.0

The Steam Mini-golf game: The game aim was for the player to rotate the valve in several repetitions in order to release steam to push the ball into the hole within a given time. The targeted exercise is shown in Figure 5. Visual cues appear on the screen to direct player's movement. Audio was used to set the rotation tempo.

Fig. 5. “Rolling a ball” exercise [49]

The game mechanics focused on improving users’ speed, rigidity, range of movement, bi-lateral movement. The game was designed to collect specific biofeedback (measured in the game and displayed in the Clinician Platform) such as range of movement of upper limbs in Euler degrees, speed in m/s2, spontaneity of movement etc. The figures (figures 6,7) below depict the first and second version of the Steam Mini-golf game.

Fig. 6. Steam Mini-golf game v1.0

Fig. 7. Steam Mini-golf game v2.0

The two cases presented above are two physiotherapy exercises, prescribed by the Parkinson's Disease Society, translated into mini-games that help engage the participant, enabling home-base rehabilitation to become more motivating and immersive. Furthermore, the clinician was provided with real-time biofeedback, realising the potential to regulate the level of difficulty of the performed action as well as to record the data for future reference and further analysis through the proposed Clinician Platform.

a. Pilot testing

There were two rounds of pilot testing conducted. Five participants diagnosed with idiopathic PD (2 women, 3 men; mean age 68.25 ± 3.5 years; disease duration, 5.4 ± 1.5 years) were recruited. All participants were on medication throughout the course of the study. Prior to commencing the study, severity of PD was assessed using both the Movement Disorder Society's revised Unified Parkinson's Disease Rating Scale (MDS-UPDRS,[7]), and the modified Hoehn & Yahr rating scale ([50], see Table

1). All participants had an MMSE (Mini Mental State Examination, [51]) score above 24, indicating no serious cognitive deficits. Participants also fulfilled the following inclusion criteria: normal or corrected-to-normal vision and hearing, no history of neurological conditions other than PD, and no musculoskeletal disorders affecting arm movement. Ethical clearance was obtained from the local psychological ethics committee, and all participants gave informed consent. The number of participants is enough to collect insights to drive the design of the games as according to Nielsen [49][50] the first five users will reveal about 85% of the problems. In a prototype design like ours, this percentage is acceptable due to the duration of the project and funding. Furthermore the iterative nature (two pilots) of our testing reduces the risk of unrevealed problem. The pilots took place in a research lab and each session lasted approximately an hour. This lab was the Movement Innovation Lab, at School of Psychology, Queen's University in Belfast. Participant information was collected prior to the study.

Table 1 Participants characteristics

Variable	*Mean ± SD*
H&Y rating scale (Stage 0-4)	*1.8 ± 0.84 (Mode = 2)*
Total MDSUPDRS	*56.60 ± 19.36*
MDSUPDRS-section I	*9.40 ± 3.05*
MDSUPDRS- section II	*10.02 ± 4.91*
MDSUPDRS- section III	*33.80 ± 10.13*
MDSUPDRS- section IV	*4.40 ± 3.84*

SD: Standard Deviation; H&Y: Hoehn and Yahr Rating Scale; MDSUPDRS: Movement Disorder Society's Unified Parkinson's disease Rating Scale; MDSUPDRS-I: Non-Motor Aspects of Experiences of Daily Living (max score: 52); MDSUPDRS-II: Motor Aspects of Experiences of Daily Living (max score: 52); MDSUPDRS-III: Functional Motor Examination (max score: 72); UPDRS-IV: Motor Complications (max score 24). Higher scores indicate more severe symptoms and progression.

Fig. 8. Patient during the field testingof rowing game

Fig. 9. Patient during the field testing of mini-golf game

During the first round of pilot testing, participants were shown and given the opportunity to familiarise with the two games and were then asked to engage with these. In addition, the authors were given the opportunity to address any issues with the motion capture technology and receive feedback on the use of the Wiimotes as MoCap devices from the patients. Each session was recorded for future reference. Also, the motion data (including Wiimote motion capture) of each game session was recorded by the system for later analysis. This data was stored in quaternion form and for each of the degrees of freedom (yaw, roll, pitch). A questionnaire was distributed after each session and a focus group took place with all study participants. The participants played each of the two games for at least five rounds with small breaks between rounds to prevent muscle fatigue. Then, they were given some time to rest and after that answer the questionnaires.

After the completion of the first pilot, all data (notes, observation video and post-study questionnaires) was analysed and the user feedback was used to amend the games accordingly. A second round of pilot testing was arranged two months after the first session with the same cohort of participants. The beta versions of the games, amended according to the participants' feedback, were presented and tested again by the same persons. Afterwards, the participants had to fill in the same questionnaire as in the first pilot and give feedback on the improved game versions. At the end of the sessions, a focus group intervened with the participants to gather as much feedback as possible through various research methods.

5 RESULTS

The data gathered from the various stages of the study, presented above, was organised, analysed and summarised in a qualitative manner. Observation notes, video recordings of the sessions and the post-study questionnaires were evaluated and conclusions were driven by that data. The games were tested individually and the results are presented for each of the games.

Game 1

The feedback and suggestions we got for the first game, namely the rowing game, can be summarised in the following points:

Table 2

Feedback	Suggestions
▪ Fun to play	▪ Introduction of score/performance progress history
• Clear Instructions	▪ Audio feedback on how to improve exercise technique
▪ Intensive exercise with a very good range of movement for upper body	▪ Improve visual aesthetics and add more game graphics
▪ High motivation	
▪ Positive comments on graphics / visual / audio cues	

The majority of participants enjoyed playing the rowing game. Participants overall commented that the game was fun to play and that the exercise, although intensive, covered a good range of exercise for the upper body:

"It feels good, it feels as the muscles here and here [pointing at the forearms on both arms] have really tighten from what we've been doing…it feels as if my arms are being used" (Participant 2)

"I have not been able to use the Wii so this game [indicating the rowing game] is very good for upper body exercise" (Participant 4)

The study participants were clearly engaged with the game and the agility required for the gameplay seemed to be fitting to their motor capacities.

"I like the movement…it feels like driving. It makes more sense making in into a driving game" (Participant 3)

"it is interesting because I do not have to hold or click anything" (Participant 5)

It was felt that playing the game increased the incentive and motivation for exercising and despite being intensive at times, participants were motivated to complete the game and to improve their score each time. Interesting dynamics were observed amongst our participants as some expressed enjoyment in trying to improve their personal best, while others were more interested in competing against each other:

"How did I do? Did I do better than participant 4?" (Participant 3)

"It would be good to be able to play against another person" (Participant 4)

"Competing with the computer would be good" (Participant 3)

The targets of the game were clear and they found the exercise intensive but appropriate for upper limb training. The users also found the audio and visual cues very helpful and commented positively on the graphics and the audio feedback.

"It is much better than last time" (Participant 3)

The audio with the beat tempo was found very useful, as it was observed when looking at the captured videos and produced performance scores/times. Generally participants rowed faster in the game when the audio tempo was increased as the game progressed:

"audio…that was useful, it gives you incentive to go the extra mile" (Participant 3)

"It seems more challenging, the pace is faster than last time" [this is due to the audio tempo incorporation, giving them the impression of a faster game pace] (Participant 2)

"sound feedback is most welcome" (Participant 1)

Another interesting piece of feedback came from one of our study participants who used to row prior his PD diagnosis and found this game as a useful tool to reminiscing and being able to follow his hobby:

"I was rowing when I was younger so I enjoy this" (Participant 4)

With respect to hobbies another participant provided the team with invaluable ideas on how the existing rowing game could be modified to create new games, which can cater for other personal hobbies whilst keeping the same rate and level of activity, such as a gardening game.

Also a number of improvements were suggested. The key one was the inclusion of a score/performance progress history, which would allow participants to compare their score with previous game sessions and see how much they have progressed:

"it would be useful if feedback is compared with previous sessions to show me how I am doing" (Participant 1)

Another suggestion was to provide the player with feedback (possibly audio feedback) on how to improve the technique (e.g. what needs to be done to score higher). Other improvements included the use of more animations, the incorporation of a 3D character graphic on the boat and being able to play against the computer. An interesting note about the overall game design feedback was that it closely reflected feedback and suggestions (e.g. on graphics improvement) one would expcted from a younger population. It was therefore very positive and at the same time unexpectedly welcome to have such responses. Indicating that older users have an equally fluent view when it comes to game play and experience.

Game 2

The feedback and suggestions received for the second game (the steam mini-golf game) can be summarised in the following points:

Table 3

Feedback	Suggestions
▪ Much more challenging exercise	▪ Improve visual feedback / cues
▪ Not very clear instructions	▪ Clockwise instead of anticlockwise movement was found more appropriate
▪ More challenging to accomplish the task	▪ More clear instructions

This second game, the steam mini-golf game, was deemed more challenging than, and not as popular as, the rowing game:

"it's much more demanding exercise" [referring to the steam golf game] (Participant 5)

"It is a fairly challenging exercise" [indicating the steam golf game] (Participant 4)

Overall it was found that the exercise underlying the game was much more challenging than that in the rowing game as it required arm movement across three different planes (coronal, transverse and sagittal plane). It was our intention to investigate a game with a more complex set of motor skills required in the gameplay in order to examine the limitations of translating the physiotherapy exercises into games. It seems that the patients were confused by the game concept. However, once the concept was explained they were motivated to accomplish the given task. This increased challenge provided participants with added incentive to win the game, however, it was deemed very difficult and tiring. The game graphics were found to be good and the clockwise movement of the arms required in the game was found to be more appropriate when compared to the anti-clockwise movement used in the first pilot version of the game. It was suggested that the mini-golf concept employed for the game design was part of the issue as it was not directly replicable and transferable to the real environment:

"it is hard relating the game [indicating the steam golf game] to a real event. Perhaps you could turn it to a sailing boat steering game" (Participant 1)

"This game [indicating the steam golf game] *would work better as a driving game, since you have to move your arms like when driving"* (Participant 4)

Participants suggested having a boat or car racing game instead, as it would enable for a clear association with a 'real-world' activity. Through discussion with the participants following the pilot sessions and their feedback, it became apparent that games which are aligned to past hobbies and activities have a greater chance of success and acceptance by people with Parkinson's disease.

6 DESIGN GUIDELINES

This section presents a set of design guidelines and best practices. These emanate from the review of the available literature and the feedback of the prototype games pilot tested.

a. Translation of exercises to games

ExerGames with challenging yet achievable goals form a great incentive and motivation for keeping active. The customisation of such games is a key element of success and significantly improves the engagement of the patients with the rehabilitation program. It was found that even in cases where participants were tired or felt slight discomfort they kept on playing the games as there were personal motivational rewards in completing them and aiming at improving the score each time. We also found that a key to a successful game design is to take Parkinson's specific physiotherapy exercises and translate them into a game. It is important that the exercise movement is not too complex and can be executed on a single plane so that the motion can be accurately captured by the Wii remotes (or other equivalent mocap system) and depicted in the game. In addition to this it is better if the game duration is relatively short or it includes little breaks to give the player time to recover and rest.

b. Familiar activities and past hobbies make the best games

We found that simple exercises movements work the best. Also when translating exercise movements to games it is most useful to choose actions that relate to familiar activities based on sport, hobbies, or other daily activities. This works well for past hobbies and activities that people with PD used to be engaged with prior to their diagnosis, as it provides them with an enabling and creative space where past habits can be followed and reinvented.

c. Adaptation and calibration

It is important that games are automatically calibrated to the range of motion of each individual player, so that the required movement and exercise level in the game is adjusted automatically to offer the player the best possible experience and level of challenge. The aim of the game should be simple but challenging with the level of difficulty gradually increasing to meet the skill level and experience of the player.

d. Game narrative: providing playful experiences

The game narrative includes the ludic aspect of the game including visual stimuli and audio output. The importance of the game narrative in accordance to enjoyment and hence engagement with the game is very high. It is a basic element of interaction and the pleasure of the human senses should always be kept in high priority. Appealing graphics, attractive scenes, charming animations and amusing sounds are essential elements of fun and directly related to the engagement of a player. Another element that should be appraised is the clear instructions and game targets. The players seem to be frustrated when they don't know how to play a game or cannot clearly see the target of it. More particularly for PD rehabilitation games, the inclusion of visual and audio feedback is a critical element in the games as they guide the player throughout and not only improve the game experience but also cognitively aid their agility.

e. Challenge and competition

Detailed feedback should be provided at the end of each game session indicating the skill level of the player and how well they have performed not only in a single game session but also offering a comparison with previous game sessions so that a progress history can be drawn. Fostering competition through the games, whether it is against oneself, the computer or another player is important in increasing player motivation and supporting people further in keeping active. Games which facilitate gameplay amongst people with PD are particularly useful as they have the potential of fostering ongoing motivation through healthy competition and a network of support through social play. In fact social games, which involve two or more people should be pursuit by researchers in this area as the benefits of such interaction can support wellbeing through a game-buddy system. In this case people with similar PD diagnosis (level, age, symptoms) can be paired to offer a positive experience and a social and community feeling.

f. PD Patient-led versus patient-centred game design

Although piloting games and game prototypes with people with PD is a useful exercise it is not the only and best approach to be adopted. The main issues with such an approach are that games are still heavily based on game designers' preconceptions and assumptions and they are tested at a late stage in the design process. With regards to the former point, despite game designers having ample experience in the design of traditional games aimed at the entertainment and leisure market they have very limited knowledge and often understanding of the often complex and diverse requirements of people with PD. Hence when designing games for use by people with PD several assumptions are often made. Obviously people with PD, their carers and therapists are the only experts in what works and what does not regarding their very specific needs. It makes sense therefore that people with PD and professionals are involved in the design of games. Critically this should be done from the early stages of the design process in order to reducing the gulf between actual user needs, expectations and game experience and play. Such a patient-led design approach can also potentially reduce the effort and cost of designing games tailored for people with PD as inappropriate ideas would be discarded in the early phases of design. Lastly involving people with PD in the design process will have positive benefits for them, as it will offer them a sense of duty, usefulness and contribution to something for the greater good.

6 CONCLUSION

This paper has presented a set of guidelines and a design framework for the design of serious games for use in the motor rehabilitation of people with PD. The proposed design guidelines were based on best practices reported in the literature and a series of pilot games designed and tested with people suffering from PD. The games were designed by translating suitable PD motor rehabilitation exercises into playful activities. The feedback received in the iterative design and testing of the pilot games revealed a series of specifications for the design and development of such games and these specifications were summarised into the proposed design guidelines for this genre of SGs.

Our research revealed that translating exercises into games that are based on familiar, playful activities and hobbies has the potential to increase the level of engagement and physical activity intensity of people with PD in therapy. To help achieve this emphasis should be placed on game narratives that incorporate well visual and audio cues that guide and encourage people with PD in the completion of the physical exercise imprinted in the game design. It is equally important to promote challenge and competition on a both individual and social level. It is critical that the game interface illustrates clearly the player performance in comparison to previous session so that progress can be visually tracked. To enable an uninterrupted and continuous positive game experience the system employed for capturing and translating the player motion into actions on the screen, should allow for automatic calibration and game adjustment based on the motor abilities of each individual user. Lastly following a PD patient-led rather a PD patient-centred design approach, where one designs with the target audience instead of for them can lead to a stronger game acceptance and adoption, saving valuable resources at the same time.

We envisage that the proposed guidelines would inform future researchers and game designers in the production of serious games that would stimulate and engage people with Parkinson's with their physical therapy.

ACKNOWLEDGEMENTS

The authors of the paper will like to acknowledge Brunel University for funding the pilot study. The authors would also like to thank Prof Cathy Craig and Dr Caroline Whyatt from Queens Belfast University for their feedback and help in the pilot studies.

REFERENCES

[1] Medtronic, About Parkinson's Disease, (2012). http://www.medtronic.com/patients/parkinsons-disease/index.htm (accessed November 19, 2013).

[2] Parkinson's_Foundation, Statistic's on Parkinson's, (2013). http://pdf.org/en/parkinson_statistics (accessed November 19, 2013).

[3] P. Andlin-Sobocki, B. Jönsson, H.-U. Wittchen, J. Olesen, Costs of disorders of the brain in Europe., Eur. J. Neurol. 14 (2007) e9. doi:10.1111/j.1468-1331.2006.01570.x.

[4] HESonline, Hospital Episode Statistics on Parkinson's HESonline NHS, (2013). http://www.hesonline.nhs.uk/Ease/servlet/ContentServer?siteID=1937&categoryID=868 (accessed November 19, 2013).

[5] Parkinson'sUK, Parkinson ' s prevalence in the United Kingdom, (2009). http://www.parkinsons.org.uk/pdf/ParkinsonsprevalenceUK.pdf. (accessed March 31, 2014).

[6] J. Jankovic, Parkinson's disease: clinical features and diagnosis., J. Neurol. Neurosurg. Psychiatry. 79 (2008) 368–76. doi:10.1136/jnnp.2007.131045.

[7] P. Ferry, M. Johnson, P. Wallis, Use of complementary therapies and non-prescribed medication in patients with Parkinson's disease, Postgrad. Med. J. (2002) 612–615. http://pmj.bmj.com/content/78/924/612.short (accessed August 08, 2014).

[8] C.L. Tomlinson, S. Patel, C.P. Herd, C.E. Clarke, R. Stowe, N. Ives, Physiotherapy intervention in Parkinson ' s disease : systematic review and meta-analysis, BMJ. 5004 (2012) 1–14. doi:10.1136/bmj.e5004.

[9] V.A. Goodwin, S.H. Richards, R.S. Taylor, A.H. Taylor, J.L. Campbell, The effectiveness of exercise interventions for people with Parkinson's disease: a systematic review and meta-analysis., Mov. Disord. 23 (2008) 631–640. doi:10.1002/mds.21922.

[10] M. van Nimwegen, A.D. Speelman, E.J.M. Hofman-van Rossum, S. Overeem, D.J.H. Deeg, G.F. Borm, et al., Physical inactivity in Parkinson ' s disease, J Neurol. (2011) 2214–2221. doi:10.1007/s00415-011-6097-7.

[11] B.G. Farley, G.F. Koshland, Training BIG to move faster: the application of the speed-amplitude relation as a rehabilitation strategy for people with Parkinson's disease., Exp. Brain Res. 167 (2005) 462–7. doi:10.1007/s00221-005-0179-7.

[12] B.G. Farley, C.M. Fox, L.O. Ramig, D.H. Mcfarland, Intensive Amplitude-specific Therapeutic Approaches for Parkinson ' s Disease, Top. Geriatr. Rehabil. 24 (2008) 99–114.

[13] L.O. Ramig, C. Fox, S. Sapir, Parkinson's disease: Speech and voice disorders and their treatment with the Lee Silverman Voice Treatment, Semin. Speech Lang. 25 (2004) 169–180.

[14] G. Ebersbach, H. Baas, I. Csoti, M. Müngersdorf, G. Deuschl, Scales in Parkinson's disease, J. Neurol. Neurosurg. Psychiatry. 79 (2006) 368.

[15] S. Fahn, R. Elton, UPDRS program members. Unified Parkinsons Disease Rating Scale, Recent dev, Macmillan Healthcare Information, Florham Park, 1987.

[16] M.J. Majsak, T. Kaminski, A.M. Gentile, J.R. Flanagan, The reaching movements of patients with Parkinson's disease under self-determined maximal speed and visually cued conditions, Brain. 121 (1998) 755–766.

[17] G.C. McIntosh, S.H. Brown, R.R. Rice, M.H. Thaut, Rhythmic auditory-motor facilitation of gait patterns in patients with Parkinson's disease., J. Neurol. Neurosurg. Psychiatry. 62 (1997) 22–26. doi:10.1136/jnnp.62.1.22.

[18] M.F. del Olmo, P. Arias, M.C. Furio, M.A. Pozo, J. Cudeiro, Evaluation of the effect of training using auditory stimulation on rhythmic movement in Parkinsonian patients — a combined motor and [18 F] -FDG PET study, Park. Relat. Disord. 12 (2006) 155–164. doi:10.1016/j.parkreldis.2005.11.002.

[19] S.M.P. Verschueren, S.P. Swinnen, R. Dom, W. De Weerdt, Interlimb coordination in patients with Parkinson's disease: motor learning deficits and the importance of augmented information feedback, Exp. Brain Res. 113 (1997) 497–508. doi:10.1007/PL00005602.

[20] S.P. Swinnen, M. Steyvers, L. Van Den Bergh, G.E. Stelmach, Motor learning and Parkinson's disease: refinement of within-limb and between-limb coordination as a result of practice, Behav. Brain Res. 111 (2000) 45–59. doi:10.1016/S0166-4328(00)00144-3.

[21] R.M. Oliveira, J.M. Gurd, P. Nixon, J.C. Marshall, Micrographia in Parkinson ' s disease : the effect of providing external cues, J. Neurol. Neurosurg. Psychiatry. (1997) 429–433.

[22] M. Holden, Virtual environments for motor rehabilitation: review, Cyberpsychology Behav. 8 (2005) 187–211.

[23] P.E. Cherniack, Not just fun and games: applications of virtual reality in the identification and rehabilitation of cognitive disorders of the elderly., Disabil. Rehabil. Assist. Technol. 6 (2011) 283–9. doi:10.3109/17483107.2010.542570.

[24] A. Sugumaran, A. Prakash, Wii can rehabilitate ?, Clin. Pract. (2011) 228–229.

[25] N. Ben Herz, The Nintendo Wii© and PD, Parkinson.org. (2008) 7–8. http://www.parkinson.org/NationalParkinsonFoundation/files/cd/cdf0b319-a28b-4082-bf07-64888dbd2c90.pdf (accessed April 21, 2013).

[26] Y. Jung, W. Li, C. Gladys, K.M. Lee, Games for a Better Life : Effects of Playing Wii Games on the Well-Being of Seniors in a Long-Term Care Facility, in: Proc. Sixth Australas. Conf. Interact. Entertain., 2009: pp. 0–5.

[27] J.S. Dhillon, C. Ramos, B.C. Wünsche, C. Lutteroth, Leveraging consumer sensing devices for telehealth, Proc. 13th Int. Conf. NZ Chapter ACM's Spec. Interes. Gr. Human-Computer Interact. - CHINZ '12. (2012) 29. doi:10.1145/2379256.2379262.

[28] J.E. Pompeu, F.A.D.S. Mendes, K.G. Da Silva, A.M. Lobo, T.D.P. Oliveira, A.P. Zomignani, et al., Effect of Nintendo Wii^{TM}-based motor and cognitive training on activities of daily living in patients with Parkinson's disease: a randomised clinical trial., Physiotherapy. 98 (2012) 196–204. doi:10.1016/j.physio.2012.06.004.

[29] K. Zettergren, J. Franca, M. Antunes, C. Lavallee, The effects of Nintendo Wii Fit training on gait speed , balance , functional mobility and depression in one person with Parkinson ' s disease, Med. Heal. Sci. Journal, MHSJ. 9 (2011) 18–24.

[30] G. Barry, B. Galna, L. Rochester, The role of exergaming in Parkinson's disease rehabilitation: a systematic review of the evidence., J. Neuroeng. Rehabil. 11 (2014) 33. doi:10.1186/1743-0003-11-33.

[31] C.H. Vuong, T. Ingalls, J.J. Abbas, Transforming clinical rehabilitation into interactive multimedia, Proc. 19th ACM Int. Conf. Multimed. - MM '11. (2011) 937. doi:10.1145/2072298.2071907.

[32] J. Annema, M. Verstraete, V. Vanden Abeele, S. Desmet, D. Geerts, I.K.U. Leuven, Videogames in therapy : a therapist ' s perspective, Proc. Sixth Australas. Conf. Interact. Entertain. (2010) 94–98.

[33] O. Assad, R. Hermann, D. Lilla, B. Mellies, R. Meyer, L. Shevach, et al., Motion-based games for Parkinson's disease patients, in: Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics), 2011: pp. 47–58.

[34] A. Camurri, B. Mazzarino, G. Volpe, P. Morasso, F. Priano, C. Re, Application of multimedia techniques in the physical rehabilitation of Parkinson's patients, J. Vis. Comput. Animat. 14 (2003) 269–278. doi:10.1002/vis.324.

[35] D. Lilla, M. Herrlich, R. Malaka, D. Krannich, The influence of music on player performance in exergames for parkinson's patients, in: Entertain. Comput. - ICEC 2012 Lect. Notes Comput. Sci., 2012: pp. 433–436. http://link.springer.com/chapter/10.1007/978-3-642-33542-6_46 (accessed August 08, 2014).

[36] G. Sanmartín, J. Flores, P. Arias, Motion capture for clinical purposes, an approach using primesense sensors, Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics). 7378 LNCS (2012) 273–281. http://link.springer.com/chapter/10.1007/978-3-642-31567-1_27 (accessed August 08, 2014).

[37] T. Martins, V. Carvalho, F. Soares, Development of a system for monitoring and tracking of physiotherapeutic movements in patients with neurological diseases, 3rd Port. Meet. Bioeng. (ENBENG), 2013 IEEE. (2013) 3–6. http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=6518414 (accessed October 20, 2013).

[38] W. Yu, C. Vuong, T. Ingalls, An Interactive Multimedia System for Parkinson s Patient Rehabilitation, in: Shumaker, Randall (Eds.), Virtual Mix. Real. - Syst. Appl. Part II, HCI 2011, Springer-Verlag, 2011: pp. 129–137.

[39] K.-J. Su, W.-J. Hwang, C.-Y. Wu, J.-J. Fang, I.-F. Leong, H.-I. Ma, Increasing speed to improve arm movement and standing postural control in Parkinson's disease patients when catching virtual moving balls., Gait Posture. (2013). doi:10.1016/j.gaitpost.2013.05.029.

[40] F.A. dos Santos Mendes, J.E. Pompeu, A. Modenesi Lobo, K. Guedes da Silva, T.D.P. Oliveira, A. Peterson Zomignani, et al., Motor learning, retention and transfer after virtual-reality-based training in Parkinson's disease--effect of motor and cognitive demands of games: a longitudinal, controlled clinical study., Physiotherapy. 98 (2012) 217–23. doi:10.1016/j.physio.2012.06.001.

[41] S. Göbel, S. Hardy, V. Wendel, Serious Games for Health - Personalized Exergames, Proc. Int. Conf. Multimed. (2010) 1663–1666. doi:10.1145/1873951.1874316.

[42] L. Geurts, V. Vanden Abeele, J. Husson, F. Windey, M. Van Overveldt, J.H. Annema, et al., Digital games for physical therapy: fulfilling the need for calibration and adaptation, in: Design, 2011: pp. 117–124. doi:10.1145/1935701.1935725.

[43] R.R. Palacio, C.O. Acosta, A.L. Morán, J. Cortez, Towards videogame design guidelines to promote significant leisure activities in Mexican older adults, Proc. 4th Mex. Conf. Human-Computer Interact. - MexIHC '12. (2012) 43. doi:10.1145/2382176.2382186.

[44] A.M.A. Lima, F. de C.C. Hirata, G.S. de Bruin, R.M.S. Mota, V.M.S. de Bruin, The influence of playing a non-reward game on motor ability and executive function in Parkinson's disease, Behav. Neurol. 25 (2012) 119–125. doi:10.3233/BEN-2011-0353.

[45] B. Bouchard, F. Imbeault, A. Bouzouane, B.J. Menelas, S. Qc, Developing Serious Games Specifically Adapted to People Suffering from Alzheimer, in: Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics), 2012: pp. 243–254.

[46] G.N. Lewis, J. a Rosie, Virtual reality games for movement rehabilitation in neurological conditions: how do we meet the needs and expectations of the users?, Disabil. Rehabil. 34 (2012) 1880–6. doi:10.3109/09638288.2012.670036.

[47] E. Tsekleves, D. Skordoulis, I. Paraskevopoulos, C. Kilbride, Wii your health: a low-cost wireless system for home rehabilitation after stroke using Wii remotes with its expansions and blender, Proc. 8th IASTED Int. Conf. Biomed. Eng. Biomed 2011. (2011) Pages: 502–509. http://www.actapress.com/PDFViewer.aspx?paperId=451737 (accessed March 31, 2014).

[48] E. Tsekleves, D. Skordoulis, I. Paraskevopoulos, C. Kilbride, A. Warland, Personalised stroke rehabilitation intervention using open source 3D software and the Wii Remote Plus, in: Proc. 9th Intl Conf. Disabil. Virtual Real. Assoc. Technol., Laval, France, 2012. http://www.icdvrat.org/2012/papers/ICDVRAT2012_SP25_Tsekleves_etal.pdf (accessed May 10, 2014).

[49] R. Webber, B. Ramaswamy, Keeping Moving - Exercise and Parkinson's, 2009.

[50] C.G. Goetz, W. Poewe, O. Rascol, C. Sampaio, G.T. Stebbins, C. Counsell, et al., Movement Disorder Society Task Force report on the Hoehn and Yahr staging scale: status and recommendations., Mov. Disord. 19 (2004) 1020–1028. doi:10.1002/mds.20213. (accessed March 31, 2014).

[51] M.F. Folstein, S.E. Folstein, P.R. McHugh, "Mini mental state". A practical method for grading the cognitive state of patients for the clinician, J. Psychiatr. Res. 12 (1975) 189–198.

[52] J. Nielsen, How Many Test Users in a Usability Study?, (2012). http://www.useit.com/alertbox/number-of-test-users.html (accessed March 31, 2014).

[53] J. Nielsen, Why You Only Need to Test With Five Users, (2000). http://www.useit.com/alertbox/20000319.html. (accessed March 31, 2014).