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Design guidelines for developing customised serious games for Parkinson's Disease rehabilitation using bespoke game sensors ☆

Ioannis Theoklitos Paraskevopoulos [a,*], Emmanuel Tsekleves [b], Cathy Craig [c], Caroline Whyatt [c], John Cosmas [d]

[a] Faculty of Science and Technology, Anglia Ruskin University, United Kingdom
[b] ImaginationLancaster, Lancaster University, United Kingdom
[c] Movement and Innovation Lab, Queen's University Belfast, United Kingdom
[d] School of Engineering and Design, Brunel University, United Kingdom

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ABSTRACT

The research presented in this paper proposes a set of design guidelines in the context of 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 rehabilitation of patients with Parkinson's Disease. 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 research paper to present guidelines for the design of serious games specifically for PD motor rehabilitation.

1. 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 and 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 is 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 people with PD with a series of options that include but are not restricted to courses of occupational therapy, physiotherapy, diet plans 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 a disease management tool often prescribed by clinicians, especially in recent years. The prescribed exercises often target particular motor symptoms such as tremor or Bradykinesia, with beneficial results. Particularly, the study of Tomlinson et al. [8] present an extensive review of physiotherapy treatments and their assessment of effectiveness and report that there is significant benefit of physiotherapy for a series of outcomes including functional activities for PD. Along the same lines, the review of Goodwin et al. [9] examined the effects

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* Corresponding author at: East Rd, Cambridge CB1 1PT, United Kingdom. Tel.: +44 (0)7879377180.

E-mail addresses: Ioannis.paraskevopoulos@anglia.ac.uk (I.T. Paraskevopoulos), e.tsekleves@lancaster.ac.uk (E. Tsekleves), cathy.craig@qub.ac.uk (C. Craig), c.whyatt@qub.ac.uk (C. Whyatt), john.cosmas@brunel.ac.uk (J. Cosmas).

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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. As expected the levels of people with PD 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, the research of Farley and Koshland [11,12] shows 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" [11], 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 the area of PD rehabilitation techniques with a focus on serious games for PD rehabilitation to 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.

2. Literature review

2.1. 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 can result in very poor performance of movements that require speed. The literature has revealed several compensatory mechanisms to help overcome such issues [16–21]. 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 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 limb coordination.

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. Moving on, the motor tasks performed in the virtual world can be transferred to the real world in most cases. In addition, VR has been found benefiting with regard to motor skills when compared to 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 same 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 and its peripherals is the one that has been predominately used, due to the popularity of its Wii Fit title in rehabilitation studies. A study by Sugumaran and Prakash [24] suggests that there is a connection between simply playing games and dopamine release [25], as the latter occurs with every kind of physical exercise [26]. Another research report [27] indicates that apart from dopamine release, physical activity is shown to improve the wellbeing of people with PD on activities of daily living such as independence and functional mobility. 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 [28] and [29], 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 [30], has shown that participants with PD using Wii Fit for certain periods of time improved significantly in UPDRS-section II, which refers to the Daily Living Activities outcome measure. Moreover, a case study by Zettergren et al. [31], 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. [32], states that ExerGaming for PD has been proven to be 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 people with PD and have been found to improve