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**Report by Steffen Walter, University Professor,
on the thesis entitled:**

***DESIGN AND VALIDATION OF A SERIOUS GAME FOR
REHABILITATION AND MONITORING OF INDIVIDUALS WITH
PARKINSON'S DISEASE***

Presented by Luanne Cardoso Mendes

Parkinson's disease is a neurological disorder that affects movement and causes movement and causes symptoms such as bradykinesia and tremor. Bradykinesia, characterized by slowness of movement, is the main motor symptom of Parkinson's disease, while tremor, a rhythmic and involuntary oscillatory movement of a part of the body, is usually the first and most troublesome motor symptom of the disease. Currently, the Movement Disorder Society Parkinson's Disease Rating Scale is currently the most widely used clinical scale for rating both symptoms. However, this type of assessment has limitations, such as such as subjectivity and reliance on experienced raters. These problems can be overcome by with the use of inertial sensors to objectively measure movement, for example, embedded in serious games, which are increasingly promising tools for rehabilitation and movement assessment. This dissertation is divided into 7 chapters.

Chapter 2 - Parkinson's Disease: An overview of Parkinson's disease will be presented in this chapter.

Chapter 3 - Serious Games for Individuals with Parkinson's Disease: The purpose of this chapter is to present a systematic review that aims to identify and evaluate the scenario of the use of serious games (SG) in the rehabilitation of individuals with Parkinson's disease (PD). This review evaluated the use of SGs for rehabilitation of individuals with PD. Several research initiatives proposed the use of these tools to assist in the treatment of symptoms arising from the disease. The solutions described in the studies assessed PD symptoms using physical tests; questionnaires/scales and observational analyses. No studies used recorded data of movements performed by players (provided by inertial sensors, for instance) during their interaction with the SG to assess any PD symptoms. Designing SGs for health is a

challenging process because they need to meet the demands of therapists and players, which are often complex and diverse. A successful game must be simple, enjoyable, customizable, have effectiveness in terms of therapy, and its design must consider the experiences of the users rather than the developers. Furthermore, the development of long-term studies with a statistically representative population is necessary for validating and generalizing the results obtained with the use of SGs. These characteristics are extremely important for the good acceptance of games by users and for the incorporation of these tools in outpatient settings.

Chapter 4 - Multidimensional Assessment Questionnaire for Individuals with Parkinson's Disease: The aim of this chapter is to present the development and structure validation of a self-assessment questionnaire that can be used remotely to assess the respondents' health condition. One of the aims of this questionnaire was to identify the respondents' main motor limitations in order to guide the development of the serious game.

A questionnaire, so-called "Multidimensional Assessment Questionnaire for Individuals with Parkinson's Disease" (MAQPD), was developed and its structure was validated by using factor analysis (FA), which allowed for grouping the questions into three domains: Activities of daily living (ADL), cognition, and pain. The final score for each respondent was calculated using the factor loadings as the weight of the questions. The respondents did not present an extremely severe level of impairment. As the instrument did not present substantial floor or ceiling effects, it can measure both the clinical worsening and improvement of the respondents. The ADLs that respondents had the most difficulty in performing were driving and household chores. Pain and cognition were also relevant aspects. In conclusion, the MAQPD is the only self-administered questionnaire found in the literature capable of being used remotely, and which can provide a detailed assessment of the general health condition of people with PD.

Chapter 5 - Serious Game for Rehabilitation and Monitoring of Individuals with Parkinson's Disease: The purpose of this chapter is to describe the architecture and organisation of the developed serious game, as well as to present the evaluation of its usability and accessibility.

This chapter presented the architecture and the usability evaluation of the RehaBEElitation serious game. The user-centered system was conceived from requirements of serious game projects, having in its conception the participation of a multidisciplinary team with experience in game development and Parkinson's disease (PD). The proposed architecture was presented using the BPM to facilitate the reproduction of the system, and to extend its application to other scenarios of use considering the evaluation of other diseases. In the same way, the heuristic evaluation presented can serve as a guide for the development of new serious games. The usability evaluation results showed that RehaBEElitation is a game that presents simple and intuitive narrative and interface, compatible with the players' mental models. This facilitated the interaction of individuals with the game and contributed with the great acceptance of the whole system. In summary, the developed system allows

the evaluation and monitoring of individuals with PD using an accessible serious game, objectively. The detailed description of the game architecture, as well as the evaluation of the game usability can help professionals from different areas to develop more efficient systems and technologies.

Chapter 6 - Objective Assessment of Bradykinesia and Tremor: The aim of this chapter is to present the objective assessment of the main motor symptoms of Parkinson's disease using the RehaBEElitation serious game.

In this chapter, bradykinesia and tremor were assessed objectively using the RehaBEElitation serious game. Response time and angular velocity proved to be very consistent variables to estimate the slowness of individuals. Patients in the ON medication state showed more reduced bradykinesia compared to patients in the OFF state. Regarding tremor evaluation, the participants of the EG in the OFF state of medication presented more tremor in comparison to the ON state, as expected. Moreover, the healthy individuals perceived less difficulty when playing as they had no or less tremor compared to the participants with PD. Serious games are effective tools for the objective monitoring of PD symptoms, providing concrete information about the progression of the disease. In summary, it can be concluded that the developed system constitutes an alternative and quite complete tool capable of assessing the main motor symptoms of PD entertainingly and objectively.

Chapter 7 - Final Considerations: Parkinson's disease is characterized by various motor and non-motor symptoms that affect the quality of life and well-being of people who suffer from the condition. This disorder is difficult to diagnose, has no cure and uses a subjective scale as the gold standard assessment tool, which can produce incorrect conclusions about patients' health status. In this sense, it is important to develop new technologies that can help health professionals monitor and assess patients, as well as improve the rehabilitation process for individual's affected by the disease. The literature review presented in Chapter 3 showed that several serious games have been developed for PD patients, but many do not take into account the experiences of the target audience, which is composed of elderly people who are not familiar with virtual technologies. Existing games generally present narratives that are incompatible with the players' mental models and are often not designed focusing on the real needs of professionals and patients. To identify the main motor, cognitive and pain limitations of PD patients, a multidimensional assessment questionnaire was developed. The questionnaire enabled us to understand which types of daily tasks patients have most difficulty in performing, as well as which cognitive and pain aspects affect them the most. This has contributed to a better understanding of the real needs of individual's affected by the disease, as well as identifying considerable motor limitations experienced by patients. The literature review and questionnaire results motivated us to develop a game considering the limitations and expectations of PD patients since the initial design stages. All of the game's features (such as the narrative, scenarios, interactions, visual and auditory feedback, and the movements required of the players) were entirely

designed with the end users at the centre of the creation process. This has certainly contributed to the wide acceptance of the tool, and to the system's high usability and accessibility. We believe that RehaBEElitation is one of the best designed serious game for people with PD described in the literature. As well as providing users with a fun and entertaining way of carrying out motor rehabilitation, the serious game is also capable of objectively assessing bradykinesia and tremor. Using information collected by inertial sensors, it was possible to quantify the main symptoms of the disease, overcoming one of the main limitations of the Movement Disorders Society–Unified Parkinson's Disease Rating Scale. The developed system is a complete and effective alternative tool capable of objectively assessing the main motor symptoms of PD. Solutions such as this one can improve users' quality of life and help healthcare professionals diagnose, monitor, and assess the patient's motor condition. The prospects for further studies include: implementing in the system the emission of reports with automated and simultaneous assessment of bradykinesia and tremor, providing real-time feedback to healthcare professionals; incorporating vibratory actuators in the glove to deliver sensory feedback to users, especially the hearing impaired, and thus improve the system's usability; and implementing new phases in the game to analyse and monitor other dimensions of PD, such as lower limb impairment, enabling a complete and objective assessment of patients using the developed system.

Option on the defense: Luanne Cardoso Mendes work is substantial and of a high scientific level. The objectives of the thesis are interesting and original. The scientific approach and the interpretation of the results are satisfactory. I hereby recommend the public defense of this thesis in order to obtain the degree of Doctor of the Université De Lorraine.

Signed in Ulm on January 09, 2024.



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