A Systematic Review of Serious Games Used for Upper-Limbs Rehabilitation of Individuals with Parkinson's Disease

Luanne Cardoso Mendes
Faculdade de Engenharia Elétrica
Universidade Federal de Uberlândia
Uberlândia, Brazil
ORCID: 0000-0001-7465-9332

Isabela Alves Marques
Faculdade de Engenharia Elétrica
Universidade Federal de Uberlândia
Uberlândia, Brazil
ORCID: 0000-0002-5025-7328

Angela Abreu Rosa de Sá
Faculdade de Engenharia Elétrica
Universidade Federal de Uberlândia
Uberlândia, Brazil
ORCID: 0000-0002-1818-8270

Camille Marques Alves
Faculdade de Engenharia Elétrica
Universidade Federal de Uberlândia
Uberlândia, Brazil
ORCID: 0000-0002-7509-1547

Rodrigo Ramos Rosa
Faculdade de Engenharia Elétrica
Universidade Federal de Uberlândia
Uberlândia, Brazil
ORCID: 0000-0001-8628-9631

Kennedy Rodrigues Lima
Faculdade de Engenharia Elétrica
Universidade Federal de Uberlândia
Uberlândia, Brazil
ORCID: 0000-0002-4243-9674

Marcus Fraga Vieira
Universidade Federal de Goiás
Goiânia, Brazil
ORCID: 0000-0001-9096-1603

Fábio Henrique Monteiro Oliveira
Instituto Federal de Brasília
Brasília, Brazil
ORCID: 0000-0002-0344-5801

Pierre Pino
Université de Lorraine
Metz, França
ORCID: 0000-0002-6191-2308

Edgard Afonso Lamounier Júnior
Faculdade de Engenharia Elétrica
Universidade Federal de Uberlândia
Uberlândia, Brazil
ORCID: 0000-0001-6293-9521

Eduardo Lázaro Martins Naves
Faculdade de Engenharia Elétrica
Universidade Federal de Uberlândia
Uberlândia, Brazil
ORCID: 0000-0003-4175-723X

Yann Morere
Université de Lorraine
Metz, França
ORCID: 0000-0002-2499-7576

Adriano Alves Pereira
Faculdade de Engenharia Elétrica
Universidade Federal de Uberlândia
Uberlândia, Brazil
ORCID: 0000-0002-1522-9989

Adriano de Oliveira Andrade
Faculdade de Engenharia Elétrica
Universidade Federal de Uberlândia
Uberlândia, Brazil
ORCID: 0000-0002-5689-6606

***Abstract*—This work consists of a systematic review of the literature whose objective is to identify and describe the main characteristics of serious games for the rehabilitation of upper limbs of individuals with PD. The search for evidence was made from the five databases: Pubmed, IEEE Xplore Digital Library, ACM Digital Library, ScienceDirect and Scopus, and after applying the criteria for inclusion and exclusion of articles, 6 publications were obtained, which represented the basis for the construction of this work. We concluded that, although there are several studies in the literature that describe and apply serious games for the rehabilitation of upper limbs of individuals with PD, there is, in most studies, a lack of methodological rigor, which compromises the efficiency of the application of the game for rehabilitation purposes.**

Keywords — Parkinson's disease, serious games, upper limbs, rehabilitation.

I. INTRODUCTION

Parkinson's disease (PD) is a brain disorder caused by the progressive loss of neurons in the substantia nigra of the midbrain which produce dopamine, a neurotransmitter responsible for the correct control of movements [1]. In this way, individuals who present deficiency in the production of dopamine, consequently present deficiencies in the control of body movements. Thus, the main clinical signs of PD are: bradykinesia, rest tremor, rigidity and postural instability [2].

There is still no cure for PD. However, despite not interrupting the progression of neurodegeneration, the treatment of the symptoms of the disease is of paramount importance for individuals to maintain or recover their functional independence [3]. The recovery of motor function, especially upper limb function, is a key factor that determines the chance of an independent life [4]. And as most activities of daily living involve the upper limbs, it is essential to improve their functional use [5].

The treatment of the motor symptoms of PD is done with the use of dopamine-based drugs, such as levodopa; with performing surgeries for more advanced stages of the disease; and with physiotherapy exercises for movement rehabilitation [6]. As patients develop progressive disability even with medical therapies and surgical interventions, physiotherapy exercises are extremely important to restore health-related quality of life in people with PD [7].

However, such exercises can be tiring, time-consuming and demotivated, contributing to patients abandoning the treatment. Furthermore, they are only effective when done daily and very intensively. Therefore, other forms of movement rehabilitation are being studied and proposed to better serve individuals with PD, such as the use of serious games (SG) [8].

SG, increasingly used in the healthcare, involve the implementation of game attributes and mechanisms to engage users while performing real tasks. SG are designed to entertain players while trying to modify some aspects of their health behavior [9]. When used for rehabilitation, due to the elements of surprise and simulation, these games potentially engage and inspire their target groups more than traditional methods [9, 10].

This article is based on a literature review whose aim is to identify and describe the main characteristics of SG for upper limbs rehabilitation of individuals with PD, identifying the pros and cons associated with their applications.

II. Materials and Methods

The first step in every scientific work that consists of a systematic review is the elaboration of a question that is sufficiently clear, objective and directed to the theme of the research to be developed. Thus, the defined question was: “What are the main characteristics, positive points and limitations of serious games used for upper limbs rehabilitation of individuals with PD found in the literature?”.

Then, the descriptors for the search for scientific articles were defined, which were: Parkinson's disease, serious games, upper limbs and motor rehabilitation. From this, the strings for the search of scientific articles were: (("serious game") AND ("Parkinson's disease") AND ("upper limbs")) and (("serious game") AND ("Parkinson's disease") AND (“upper limbs”) AND (“motor rehabilitation”)). It is important to emphasize that the searches were performed with the descriptors in English, Portuguese and Spanish, in the following databases: Pubmed, IEEE Xplore Digital Library, ACM Digital Library, ScienceDirect and Scopus.

The searches for scientific papers were conducted between May and July 2021. No specific time interval was defined for the publication period in order to have access to the largest possible number of results.

All articles found in each search were added to a spreadsheet, this being the inclusion criterion adopted. Then, the process of exclusion of articles was started, adopting three criteria:

- Repetition of articles;

- Inadequacy of the proposed theme;

- Articles that did not contribute significantly to the research, or with incomplete texts.

The PRISMA tool was used for the identification, selection, eligibility, and inclusion of articles. It presents preferred reporting items for systematic reviews and meta-analyses.

It is also important to consider in a systematic review the quality of the selected studies. This measurement was obtained following some criteria [11], defined by the evaluation of the following questions according to a score of 1 point for YES; 0.5 point for PARTIALLY; and 0 for NO.

A - Is the article based on research, or is it based only on the opinion of specialists?

B - Is there a clear statement of the research objectives?

C - Was the methodology used adequate to meet the research objectives?

D - Was the participant recruitment strategy appropriate to meet the research objectives?

E - Was there a control group to which the results could be compared?

F - Was the data analysis rigorous enough?

G - Was there a clear statement of results?

III. Results

This section will be divided into three subsections: the first, presents the processes and quantity of articles in each stage after applying the exclusion criteria; the second subsection describes the results found in the studies; and finally, the third subsection presents the qualitative evaluation table, based on the criteria described above.

A. Selection process of studies included

Initially, the search presented 598 works. After excluding those that were repeated, 373 remained, and these, 353 were selected primarily. Then, with the removal of those that did not fit the theme, the number of studies reduced to 114. Then, 108 with full text were excluded for not describing the characteristics of the games, making it impossible to identify positive and negative aspects of the application. Thus, 6 articles constituted this work. The step-by-step of deleting studies in each stage is represented by Fig. 2.

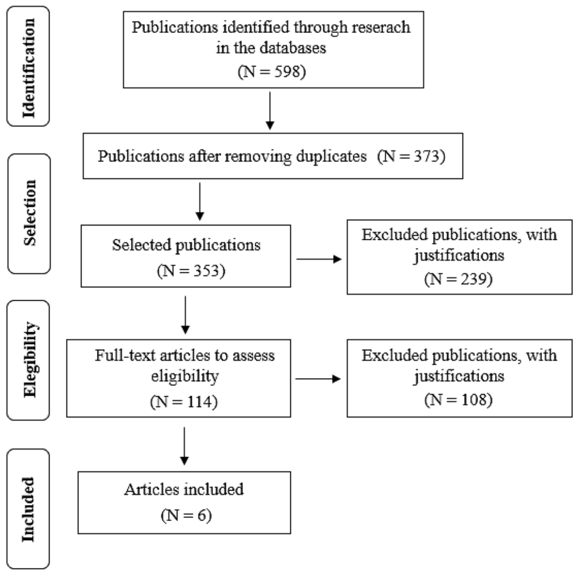

Fig. 1. Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA)

B. Description of study results

In the study by Fernández-González and collaborators [12], the Leap Motion sensor was used to capture users' hand movements and different virtual environments were created using Unity 3D software. In total, six games were developed, described below: Piano Game – presents a virtual piano keyboard with ten keys, each corresponding to a single finger in each hand, which must be touched with the corresponding finger when a key presents a light signal (light up); Reach Game – several cubes are shown in different spatial positions, which stand out, indicating the target to be touched by the user; Sequence Game – a sequence of cubes is presented to the user, who must memorize the sequence and repeat it hitting the cubes in the same order presented; Grasp Game – the player must grab highlighted cubes, transport them to a red circle in the center of the screen and release the cubes only when they touch the red circle; Pinch Game – when a cube is highlighted on the screen, the user must bring the hand closer to the target cube and, using the pinch movement, decrease it, until the cube disappears; Flip Game – the player, imitating a waiter holding a tray, must turn the palm of the hand downwards so that the cube detaches from the virtual tray and falls to the ground. For this study, 23 patients with PD, in stages II-IV of the Hoehn & Yahr scale, were randomized into two groups: an experimental group that received treatment based on SG (n=12) and a control group that received specific intervention for upper limbs (n=11). The authors concluded that the system can be a viable rehabilitation tool for upper limbs in patients with PD, but emphasized that further studies are needed to confirm the results. Furthermore, the developed games do not provide feedback to players, as well as different difficulty levels.

The study developed by Cikajlo et al. [13] presented a game for telerehabilitation of upper extremities using the Kinect sensor. The system, developed with the Unity game engine, adapted the game's difficulty level in real time. The goal of the Fruit Picking game was to collect virtual apples before they fell from the virtual tree and place them in the basket, located at the bottom of the screen. The participant was instructed to raise his/her arm, open the hand and try to grab the virtual apple by closing his hand. The participant moved to the next difficulty level when he successfully collected 15 apples three consecutive times. The higher the difficulty level, the more apples ripened and fell faster from the tree. The researchers found that only seven of the 26 study participants could set up the equipment themselves at home. Furthermore, the clinical results were statistically significant and considered clinically significant. The findings led to preliminary conclusions that the game is feasible and effective, but the authors reported some limitations present in the study: although the preliminary instructions for use and testing with each participant took place within the clinical environment so that patients could learn how to use the system at home independently, problems were found with the Wi-Fi connection, which caused the software not to register and transfer the collected data; the users' experiences or motivations were not evaluated, a fact that could provide additional information and reveal system weaknesses in a real way; as the study did not have a control group, it was not possible to state that the game would be better than a conventional approach. Finally, the researchers argued that future studies should be performed with a larger group of participants to confirm the clinical value of the approach.

Bank et al. [14] used the Leap Motion sensor for tracking players' hand movements, and the virtual content of the games was visualised using a Head-Mounted Display (HMD). Three different games were created using Unity 3D software: Balloons – the player should tap twelve balloons displayed at various positions within the interaction space at random depths (one at a time, in predefined order) as quickly as possible; Melody Cubes – the player was asked to move opaque cubes into empty cubes, placed in various positions within the interaction space, and when an opaque cube touched an empty cube of corresponding size and color, the cube placement was considered successful; Hungry Squirrel – the player was asked to place 16 nuts in a virtual basket positioned alternately in the upper or lower half of the interaction space, and an obstacle (virtual squirrel) was placed between the starting position of the nut and the basket. Ten PD patients, ten stroke patients and ten healthy age-matched controls participated in this study. As expected, the PD patients moved more slowly than the controls and needed more time for task completion. No differences were observed between stroke patients and controls, perhaps because the motor impairments in this group of patients were relatively mild. Although the games provided feedback to users, they did not have different levels of difficulty. The authors concluded that many steps still need to be taken for games to be incorporated into clinical practice, such as greater sensitivity to differences between groups, understanding of clinical assessments of motor/cognitive impairments, and assessment of test-retest reliability.

In the study by Allen et al. [15] a home games program designed specifically for people with PD using Unity 3D was developed. The first game, Marshmallow, required participants to remove the correct marshmallow from the stick at the correct time. So, the strategy of this game was focused on the correct response time of the players. The Chicken game, on the other hand, required participants to pick up eggs by moving the craft to the correct location as quickly as possible, once the previous egg had been picked up. The strategy of this second game was focused on the players' quick movement. In both games, participants received auditory and visual feedback to help them improve their performance, and each game had four levels of difficulty. Thirty-eight participants with PD were randomized into two groups: experimental (n=19), who interacted with the games at home, three times a week for 12 weeks; and control (n=19), who received only usual care and continued with their routine activities. The authors observed that the developed games were acceptable and safe, but did not translate into improvement in the performance of functional activities. Thus, the intervention was feasible, but participants would have preferred greater variety in the games provided. According to the researchers, the results of this trial highlight the need to consider the specificity of task practice and long-term adherence when designing future games interventions.

The work of Foletto, d'Ornellas and Prado [16] used Unity software to develop three games for fine motor skill rehabilitation programs: Pinchiken – the player must basically pinch the eggs that appear on the ground and place them in the correct nest, indicated by a light effect; Finger-Hero – in this game there are four tracks, each with a colored flower at its end and each flower is associated with one of the four fingers of the hand (index, middle, ring and little finger). The game randomly generates bees that move towards the flowers in each lane. The player must execute the thumb opposition movement with the correct finger and at the moment when the bee is on the flower of the respective lane; Grabduzeedo – the player controls by hand a spaceship whose abduction beam can be activated and deactivated using the grab and release gestures. The objective is to abduct (by closing the hand) the sheep on the right terrain of the screen, and move it to the fenced platform on the left (by opening the hand). The prototypes were tested by 20 healthy individuals, from 20 to 45 years of age. The results indicated that the experience of the three developed games are similar, allowing the therapist to apply them in therapies with consistency. However, the authors concluded that this work is limited to the evaluation of the player experience and that, therefore, further work should be conducted to assess the functionality and validity of the games as a rehabilitation tool. In addition, the researchers pointed out that future work should investigate whether the SG experience is satisfactory for people with PD. Also, they stressed that the aesthetic and mechanical aspects of the game should be improved. The games provided visual feedbacks to users, but did not present different levels of difficulty.

Finally, Chen et al. [17] developed an immersive virtual exergame for finger motor training and hand-eye coordination, using Unity as the game engine. The game shows balloons in different colors and backgrounds, and is based on the task of hitting the target: the user can move controllers to aim at the balloons and use their finger to press the trigger and shoot. Visual and tactile feedbacks are provided to the users visually and via the controllers. Five early stage PD patients participated in the study, and there was no control group. The results indicate that immersive exergames are a promising tool for patients with PD. However, players reported possible usability problems: they stated that the game was unengaging and unappealing, as it lacked different backgrounds, settings, music and colors. The small number of participants in the evaluation and the lack of a control group did not allow more effective conclusions to be drawn. In summary, the authors concluded that more user testing with larger numbers of participants and longitudinal studies are needed to improve the game's usability and understand its effects on improving hand-eye coordination and finger movements.

C. Qualitative evaluation

Regarding the qualitative analysis of studies, Table 1 presents the scores for each study for each item evaluated, as well as the total scores for studies and items. The "Total" column refers to the sum of scores of evaluated items in each study, and the "Total" row refers to the sum of scores of all studies for each evaluated item.

TABLE I. ITEMS FOR QUALITATIVE EVALUATION

Study	A	B	C	D	E	F	G	Total
[12]	1	1	1	1	1	1	0.5	**6.5**
[13]	1	1	0.5	0	0	0.5	1	**4**
[14]	1	1	1	1	1	0.5	1	**6.5**
[15]	1	1	1	0.5	1	0.5	1	**6**
[16]	1	1	0	0	0	0.5	0.5	**3**
[17]	1	1	0	0	0	0.5	0.5	**3**
Total	**6**	**6**	**3.5**	**2.5**	**3**	**3.5**	**4.5**	

IV. DISCUSSION

From the analysis of works included in this review, it is possible to observe that SG are instruments widely used as alternative forms of movement rehabilitation. In addition to training body movements, games have the ability to exercise the brain and contribute significantly to the motor and cognitive improvement of patients with PD.

It is important to emphasize the need for the development of a wide variety of games for rehabilitation purposes, since as more patterns are learned, more novelty is needed to make the game attractive. Thus, the existence of games with different proposals, narratives, scenarios and mechanics are very important to meet different demands. In addition, SG for the movement rehabilitation of individuals with PD should be developed taking into account that the patients who will use them are, in great majority, elderly. Thus, games with simpler and uncomplicated interfaces tend to be better accepted by these individuals.

Although many studies have presented a control group to compare the results with an experimental group, the recruitment strategy for these patients was inadequate, as shown in Table 1 (the item with the lowest score among the others evaluated was D, with only 2.5 points). Furthermore, it is also important to note that, in most studies, the participants were not randomly allocated into groups, which may contribute to the lack of experimental methodological rigor in the studies developed.

V. CONCLUSION

The objectives of this study were to identify and describe the main characteristics of serious games for the upper limbs rehabilitation of individuals with PD.

Based on the results, it is possible to conclude that there are several studies that address the use of serious games for the rehabilitation of patients with PD, and that they contribute significantly to the treatment of symptoms of the disease. However, most studies showed low methodological rigor and the SG developed did not present, in general, customizable features.

ACKNOWLEDGMENT

The present work was carried out with the support of the National Council for Scientific and Technological Development (CNPq), Coordination for the Improvement of Higher Education Personnel (CAPES – Program CAPES/DFATD-88887.159028/2017-00, Program CAPES/COFECUB-88881.370894/2019-01, Program CAPES/COFECUB-88887.612297/2021-00 and Program CAPES/COFECUB-88887.628121/2021-01) and the Foundation for Research Support of the State of Minas Gerais. A. O. Andrade is fellow of CNPq, Brazil (304818/2018-6).

REFERENCES

[1] M. Armstrong, and M. S. Okun, "Diagnosis and treatment of Parkinson disease: a review," Jama, vol. 323, no. 6, pp. 548-560, 2020.

[2] D. W. Dickson, "Neuropathology of Parkinson disease," Parkinsonism & related disorders, vol. 46, pp. S30-S33, 2018.

[3] W. Oertel and J. B. Schulz, "Current and experimental treatments of Parkinson disease: A guide for neuroscientists," Journal of Neurochemistry, vol. 139, pp. 325–337, October 2016, doi: 10.1111/jnc.13750.

[4] J. M. Veerbeek, G. Kwakkel, E. E. van Wegen, J. C. Ket, and M. W. Heymans, "Early prediction of outcome of activities of daily living after stroke: a systematic review," Stroke, vol. 42, no. 5, pp. 1482-1488, 2011.

[5] P. L. Choo, H. L. Gallagher, J. Morris, V. M. Pomeroy, and F. Van Wijck, "Correlations between arm motor behavior and brain function following bilateral arm training after stroke: a systematic review," Brain and behavior, vol. 5, no. 12, pp. e00411, 2015.

[6] D. K. Simon, C. M. Tanner, and P. Brundin, "Parkinson disease epidemiology, pathology, genetics, and pathophysiology," Clinics in Geriatric Medicine, vol. 36, no. 1, pp. 1–12, February 2020, doi: 10.1016/j.cger.2019.08.002.

[7] C. L. Tomlinson et al., "Physiotherapy versus placebo or no intervention in Parkinson's disease," Cochrane Database of Systematic Reviews, no. 7, 2012.

[8] S. Flynn, P. Palma, and A. Bender, "Feasibility of using the sony playstation 2 gaming platform for an individual poststroke: a case report," J. Neurol. Phys. Ther., vol. 31, no. 4, pp. 180–189, 2007, doi: 10.1097/NPT.0b013e31815d00d5.

[9] T. Korhonen, R. Halonen, T. Ravelin, J. Kemppainen, and K. Koskela, "A Multidisciplinary Approach To Serious Game Development In The Health Sector," MCIS 2017 Proc., September 2017.

[10] D. Thompson et al., "Serious video games for health how behavioral science guided the development of a serious video game," Simul.

Gaming, vol. 41, no. 4, pp. 587–606, August 2010, doi: 10.1177/1046878108328087.

[11] T. Dybå, T. Dingsøyr, "Empirical studies of agile software development: a systematic review," Information and Software Technology, vol. 50, pp. 833-859, 2008, doi 10.1016/j.infsof.2008.01.006

[12] P. Fernández-gonzález, et al., "Leap motion controlled video game-based therapy for upper limb rehabilitation in patients with Parkinson's disease: a feasibility study," Journal of neuroengineering and rehabilitation, vol. 16, no. 1, pp. 1-10, 2019.

[13] I. Cikajlo, et al., "Can telerehabilitation games lead to functional improvement of upper extremities in individuals with Parkinson's disease?," International journal of rehabilitation research, vol. 41, no. 3, pp. 230, 2018.

[14] P. J. M. Bank, et al., "Patient-tailored augmented reality games for assessing upper extremity motor impairments in Parkinson's disease and stroke," Journal of medical systems, vol. 42, no. 12, pp. 1-11, 2018.

[15] N. E. Allen, et al., "An interactive videogame for arm and hand exercise in people with Parkinson's disease: a randomized controlled trial," Parkinsonism & related disorders, vol. 41, pp. 66-72, 2017.

[16] A. A. Foletto, M. C. D'ornellas, A. C. Prado, "Serious games for Parkinson's disease fine motor skills rehabilitation using natural interfaces," In: MEDINFO 2017: Precision Healthcare Through Informatics: Proceedings of the 16th World Congress on Medical and Health Informatics. IOS Press, pp. 74, 2018.

[17] W. Chen, et al., "An immersive virtual reality exergame for people with Parkinson's disease," In: International Conference on Computers Helping People with Special Needs. Springer, Cham, pp. 138-145, 2020.