A Pilot and Feasibility Study of Virtual Reality as Gamified Monitoring Tool for Neurorehabilitation

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Abstract. This research work focuses on the collection of indicators (biomarkers) related to the use of virtual reality among participants with different age ranges. The key aim is to monitor participants' psychomotor skills, especially wrist, elbow, and shoulder movements. All the obtained data have been collected and stored in bimodal form. It is worth mentioning a strong gamification work to achieve a total immersion effect for participants. Likewise, the scenarios must be fun, entertaining to the participant. To obtain these features, two serious games based on medieval sports games such as archery and javelin throw have been developed. To apply these two serious games, the participant uses two wireless actuators, called motion controllers, whose control is based on movement, and virtual reality goggles. The data set is composed of eight normative participants of different ages. Also, these participants at the end of the session answered a complete questionnaire. This survey provides valuable and extrapolate information on the use of virtual reality as a vehicle for monitoring the participant's psychomotor skills. For this reason, future research works will attempt to adapt it with patients with neurodegenerative diseases such as Parkinson's, Alzheimer's, or ALS to carry out longitudinal studies.

Keywords: Monitoring · Virtual reality · Serious games · Parkinson disease

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1 Introduction

Today, new devices are coming to the market as entertainment tools such as virtual reality goggles, trackers, cell phones and tablets. However, these devices can be used not only for gaming but also for rehabilitative functions. Likewise, the number of virtual reality devices sold in the last five years has increased considerably [12]. In addition, large multinational social networking companies such as Facebook, also known as Meta, have acquired leading companies in the manufacture of virtual reality googles (e.g., Oculus). This fact favors a democratization of prices and that these devices, little by little, reach all households. This is a favorable point for the development of new longitudinal monitoring applications based on these new devices.

Applications using virtual reality and several trackers have begun to stand out in recent years [9,13]. What started out as an exclusive and very expensive technology, due to the high cost of both the virtual reality googles and the high-performance personal computer (PC) that these applications need to work, is now becoming cheaper and better, allowing many more people to start developing using this type of device. However, the use of this technology is not new and many researchers have used it in recent years. In the following, we will present some of the most interesting research works for the monitoring of neurodegenerative diseases such as Parkinson's, using these kinds of devices.

Docks et al. [3] propose a review was to determine the effectiveness of virtual reality (VR) exercise interventions for rehabilitation in Parkinson's disease (PD). The authors determine that VR interventions may lead to greater improvements in step and stride length compared with physiotherapy interventions. Fernández-González et al. [4] also use Leap Motion Controller® (LMC) in order to test its effectiveness to PD patients. The preliminary findings show the amelioration of coordination and rapidness of motion in those patients. Latorre et al. [7] uses the Kinect v2-based system to complement gait assessment in clinical settings. They conclude that is could be an affordable alternative.

Studies on the use of devices such as 3D Oculus Rift CV1 or Leap motion controller to improve patients' quality of life are growing. Cikajlo and Peterlin Potisk [2] present the use of these devices to study functional improvements, motivation aspects and clinical effectiveness. Indeed, Campo-Prieto et al. [1] examine if the VR games can be used to rehabilitate PD patients. They conclude that games improve the clinical situation of patients without having adverse effects.They also indicate that patients welcome the games positively. Likewise, Imbimbo et al.[6] test that VR rehabilitation improve walking and balance of patients affected by idiopathic PD. The authors conclude that there is a correlation between the use of VR and the patient improvement.

On its turn, Lina et al. [8] and Wang et al. [14] propose a review of the effectiveness of virtual reality interventions in PD patients. Those studies take into account balance and gait in people with Parkinson's disease. Both of them conclude that there are benefits but further studies are necessary as the results are not conclusive in terms of gait. Other research work in which VR rehabilitation is used is the Pazzaglia et al. work [10]. They resolve that VR rehabilitation is more feasible than the conventional rehabilitation. On the other hand, the results of the use of VR are coming slowly. Severiano et al. [11] study the rehabilitation with virtual reality games.The authors finds that the Tightrope Walk and Ski Slalom virtual games benefices patients. Finally, Hawkins et al. [5] present a study in which they analyze how PD interacts using VR comparing to healthy controls participants.

2 Objectives

The main objective of this case study focuses on capturing a set of features related to the locomotor capacity of the participant's upper and lower trunk, using two serious games developed for virtual reality. In order to evaluate the effectiveness of these two games a comprehensive questionnaire has been answered by the participants, asking about ease of use, intelligibility of the exercises, motion sickness, entertainment, degree of immersion, graphic quality, among others. In this way, with the feedback obtained, longitudinal studies can be carried out with future patients with neurodegenerative diseases.

3 Methods and Materials

3.1 Participants

The number of participants in this case study was eight. Three males (30 ± 8 years old) and five females (30.4 ± 6.31 years old). This meager number of participants was due to the impossibility of conducting such a study in Parkinson's associations because of the active state of alarm due to the global pandemic by COVID-19. Note that technical participants are considered to be all those who have studied technological disciplines such as computer science, video games, industrial or telecommunications engineering, etc. This factor may influence their experience and handling with the device, offering a better adaptation for the performance of the tests. It should be noted that the number of females is higher than that of males, an irregular situation for this type of studies.

3.2 Frameworks and Hardware

The VR goggles used in this research work were the Lenovo Explorer googles that use Windows Mixed Reality technology. This kind of technology combines virtual reality with augmented reality. In addition, this technology is compatible with most platforms and libraries for video games such as SteamVR. It is a component that facilitates the use of virtual reality by providing both an interface for selecting games and playing them, as well as a series of libraries that can be used free of charge to program new applications that automatically integrate with Steam platform. This library has been used throughout the development of the video game to handle all the built-in VR elements. It has a version compatible with the Unity 3D game engine.

As aforementioned, VR technology requires a very high-performance computer to work properly. This means the computer should be able to maintain high refresh rates at high resolutions (90 frames per second at least). On the contrary, the participant could experiment with what is called motion sickness which provokes dizziness, disorientation, or loss of balance. The computer used while performing the test was a desktop computer that contained a motherboard AMD Ryzen 2700X with 8 cores, running at 3.6 GHz, and it was powered by 16 Gigabytes of RAM DDR4. About the graphics card, it was an Nvidia RTX 2080 which was one of the top graphic cards available at the moment.

Finally, the data collected by the video game were stored in two different databases, one local and the other remote. This option was developed because an Internet connection could not be guaranteed during the performance of tests.

3.3 Description of Two Scenarios

The study case consists of two complete scenarios, each one of them designed keeping in mind the kind of movement desired for the participant to collect high-quality locomotor biomarkers. During each level, the participant has to complete different challenges by performing several actions across all scenarios, using the hands to interact with the virtual world. Both of them involve the entire arm of the participant (i.e., from the hand to the shoulder). The first test focuses the attention on performing a horizontal pull (i.e., noak the bow with an arrow and shoot it). The second test is based on a horizontal push (i.e., throw a spear as far as possible). These two scenarios are discussed as follows.

Kyūdō. In this level, the participant spawns inside the parade ground of a medieval castle, looking towards a bulls-eye as is shown in Fig. 1a. On the right side, there is a table with a bow on top that has to be grabbed following the instructions displayed on the controller. This first action allows the participant to interact with the environment and gradually get used to it. The GUI shows different indications to perform the exercises of the level.

Once the participant has grasped the bow placed on the table (see Fig. 1a), the bow and arrow will appear in the hands automatically. The tutorial also teaches the participant how to shoot an arrow and achieve the bull-eye without the help of the researchers. To perform this task, the participant has to pull the trigger of the controller and place the arrow next to the bow. Next, the arm holding the arrow will pull the arm taut, performing the effect of loading the bow (see Fig. 1b). Finally, when the user releases the finger from the controller, the arrow will be shot. Consequently, the participant performs a horizontal pulling movement. It is logical to think that the ultimate aim of this test is to hit the bull-eye as often as possible. Once three hits have been achieved, the bull-eye will be moved to another position on the stage but at a greater distance. This forces participants to raise and lower their arms to perform a parabolic shot. Finally, the participant can end the level at any time by leaving the bow on the table.

(a) Virtual scenario. (b) Real scenario.

Fig. 1. Point of view of the participant at the Kyūdō scene.

As shown in Fig. 2, the main indicators allow the collection of the coordination between wrist, elbow, and shoulder, as well as the time spent in performing the movements. It is noteworthy how these features provide information about relevant movements such as the circumduction movement produced when the bow is caught and the pronation of the forearm when the bowstring is pulled. Likewise, secondary data such as hits, impact location, and head mobility are gathered too.

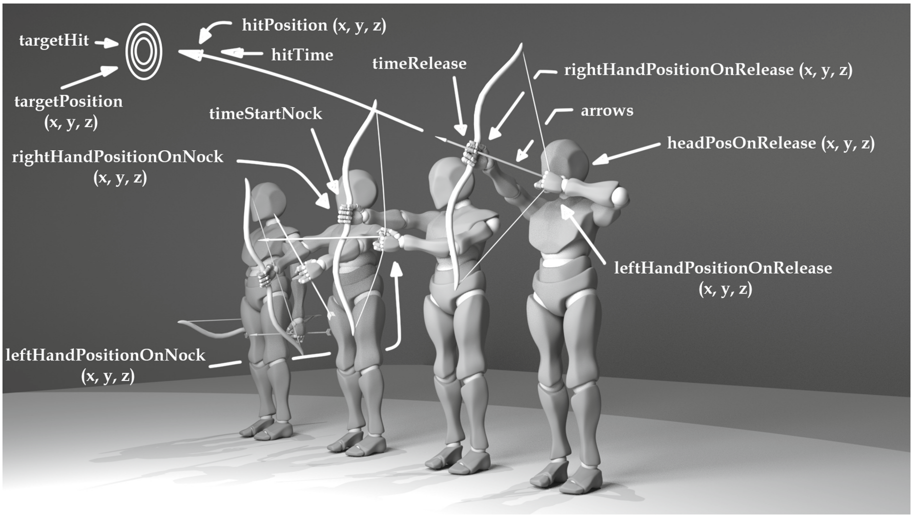


Fig. 2. Representation of movement and gathering of main indices collected, using the Kyūdō level.

Gungnir. This level takes place on a dock where the participant spawns looking at the sea with a bunch of spears, standing on one side as can be seen in Fig. 3.

Following the instructions of the tutorial about the motion controller, the participant has to grab a spear and throw it into the sea. Thus, the participant carries out a throwing movement based on the horizontal push. As soon as the spear collides with the sea, a score will appear and show the total distance made by the spear. The objective is to throw each spear the furthest the participant can do in order to make the highest score. This level will finish after the participant has thrown six spears.

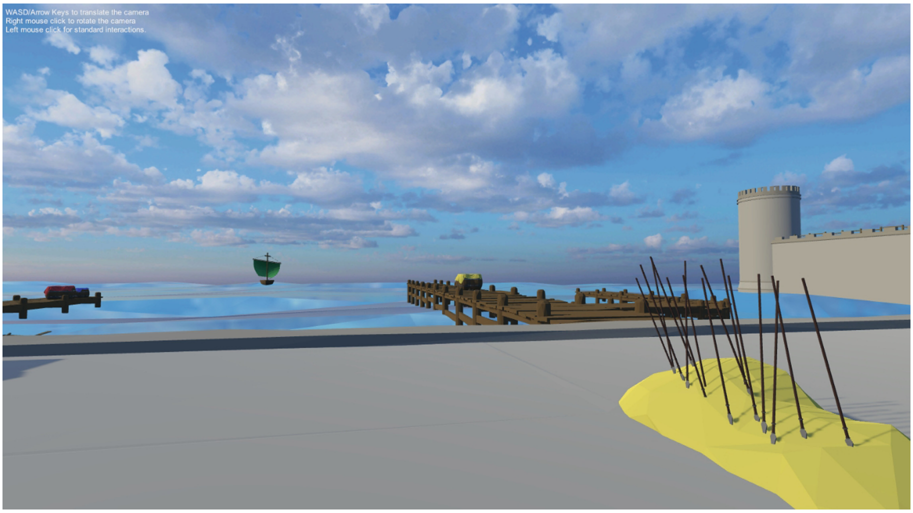


Fig. 3. Point of view of the participant at the Gungnir scene.

As shown in Fig. 4, the coordination between the arm joints and the time spent in the execution of the movements are saved in database. As aforementioned in the Kyūdō level, both the circumduction movement and the pronation of the forearm are performed when the spear is picked up, positioned and throwed. In addition, secondary data such as maximum height reached and throwing distance or number of throws are collected too.

3.4 Indices Collected

More than 60 features are collected between the two scenarios. All values obtained are related to the virtual world. The only way a participant may interact with the virtual environment is by using motion controllers, VR goggles, and headphones. The position of each device is recorded in all axes of the virtual world (i.e., X, Y, Z). Note that the position of the controllers is relative to that of the position of the goggles. However, other characteristics, referring to the gamification aspect, are collected such as the number of hits on the bull-eye, distance reached with spears, etc. These data are not binding for the study, however, they offer a more immersive experience for the participants.

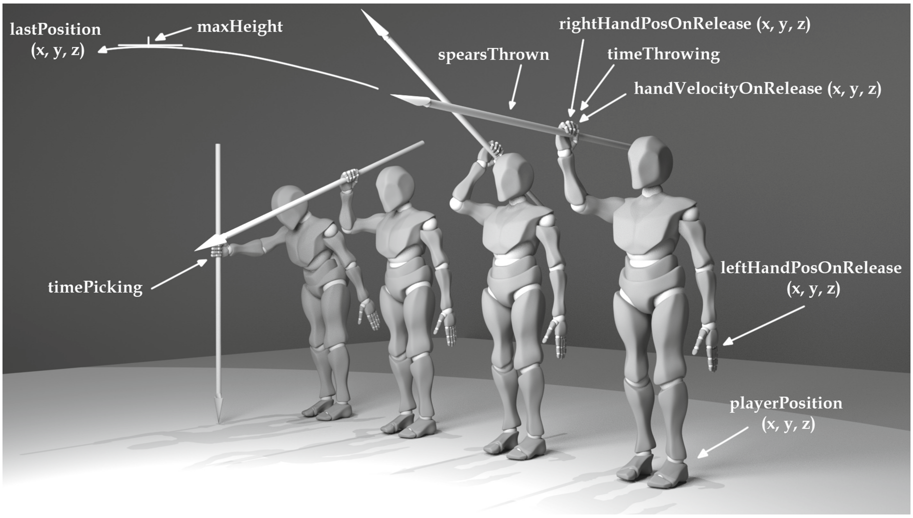


Fig. 4. Representation of movement and gathering of main indices collected, using the Gungnir level.

3.5 Questionnaire

In order to quantify the degree of achievement of the objectives, a questionnaire was elaborated taking into account some of the most important points in the development of VR simulators such as level design, font size, listening to music while using VR goggles, lighting, texturing. All these questions were directed to avoid the symptoms of motion sickness in the participants. On the other hand, other questions about usability, user-friendliness, entertainment were also asked to the participants. Finally, the participants had the opportunity to rate the scenarios with Likert scale.

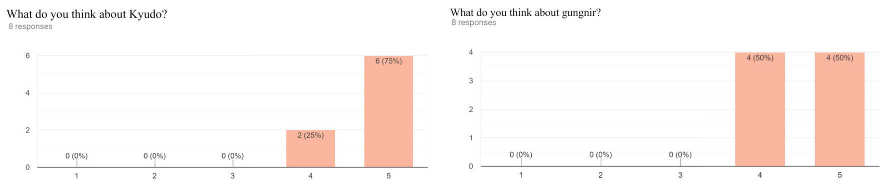
4 Results

Once the introduction to the scenarios and the questionnaire have been completed, the main results obtained from the responses of the study participants will be presented.

First, five out of the eight participants were not regular gamers. This was considered very relevant due to the possible feedback obtained on the ease of use for future trials. Also, three-quarters of the participants had used VR goggles before.

Next, they were asked several questions about the countermeasures taken to avoid motion sickness. On the one hand, they found the music to be in keeping with the game presented in both scenarios. Also, the font size was considered adequate and did not require modification. On the other hand, the open level design and the refresh rate achieved were highly rated.

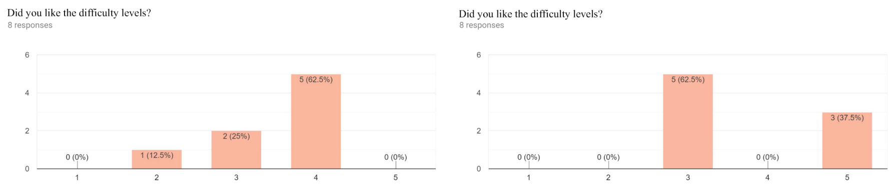
The following section of the questionnaire focused on direct questions about each of the scenarios presented. Firstly, they found the tutorials for both levels to be concise and generally easy to follow. However, 25% of the participants found the controls difficult in the spear scenario (Gungnir) and 12.5% in the bow scenario (Kyūdō). The most applauded game among the participants was the bow (Kyūdō) game, obtaining on six occasions a five-point rating and on two occasions a four-point rating on a Likert scale (see Fig. 5a). The game of the spear (Gungnir) obtained a 50% score between four and five points on a Likert scale (see Fig. 5b).



(a) Outcomes of Kyūdō. (b) Outcomes of Gungnir.

Fig. 5. Graphical abstract about the results accomplished of participants.

However, when it comes to the levels of difficulty, the opinions of the participants were more disparate. For example, in the case of the archery game, five out of the eight participants scored four out of five for the levels of difficulty, two out of eight scored three, and finally, one participant rated two out of five, i.e., the participant found the levels difficult to achieve (see Fig. 6a). In turn, in the case of the spears, the opinions were mostly neutral, with 62.5% of the participants assessing with three points out of five. The rest of the participants gave an excellent score to the level design of this scenario (see Fig. 6b).



(a) Difficulty levels (Kyūdō). (b) Difficulty levels (Gungnir).

Fig. 6. Graphical abstract about the results accomplished of participants.

5 Conclusion

This study aims to present two serious games based on virtual reality technology as a longitudinal monitoring tool. To observe their feasibility, a small corpus was carried out with a set of close participants. The reason lies in the impossibility of access to neurodegenerative disease associations due to the pandemic and the active alarm state at the time of this study.

It appears that the questionnaire data provide positive feedback on the design and development of the two scenarios. The various levels seem easy to understand and use. Therefore, it seems logical to think that future the target group of participants (non normative) will also be of the same opinion. Likewise, one of the key points of this research work is that none of the participants who collaborated in the various tests suffered from motion sickness. It should be noted that this type of reaction is very detrimental and dangerous for the future work we want to carry out with the target population.

Given the outcomes accomplished, it seems to be adequate to develop more scenarios to gather different information about the locomotor system of participants. In addition, more in-depth work on the indicators collected and their potential use for monitoring should be carried out in future research.

Finally, under the current circumstances, we could say that the first step of the research work has been achieved with relative success.

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References

1. Campo-Prieto, P., Rodríguez-Fuentes, G., Cancela-Carral, J.M.: Can immersive virtual reality videogames help Parkinson's disease patients? A case study. Sensors **21**(14), 4825 (2021)
2. Cikajlo, I., Peterlin Potisk, K.: Advantages of using 3d virtual reality based training in persons with Parkinson's disease: a parallel study. J. Neuroeng. Rehabil. **16**(1), 1–14 (2019)
3. Dockx, K., et al.: Virtual reality for rehabilitation in Parkinson's disease. Cochrane Database Syst. Rev. (12) (2016)
4. Fernández-González, P., et al.: Leap motion controlled video game-based therapy for upper limb rehabilitation in patients with Parkinson's disease: a feasibility study. J. Neuroeng. Rehabil. **16**(1), 1–10 (2019)
5. Hawkins, K.E., Paul, S.S., Chiarovano, E., Curthoys, I.S.: Using virtual reality to assess vestibulo-visual interaction in people with Parkinson's disease compared to healthy controls. Exp. Brain Res. **239**(12), 3553–3564 (2021)
6. Imbimbo, I., et al.: Parkinson's disease and virtual reality rehabilitation: cognitive reserve influences the walking and balance outcome. Neurol. Sci. **42**(11), 4615–4621 (2021)
7. Latorre, J., Colomer, C., Alcañiz, M., Llorens, R.: Gait analysis with the Kinect V2: normative study with healthy individuals and comprehensive study of its sensitivity, validity, and reliability in individuals with stroke. J. Neuroeng. Rehabil. **16**(1), 1–11 (2019)

8. Lina, C., et al.: The effect of virtual reality on the ability to perform activities of daily living, balance during gait, and motor function in Parkinson disease patients: a systematic review and meta-analysis. Am. J. Phys. Med. Rehabil. **99**(10), 917–924 (2020)
9. O'Neil, O., et al.: Virtual reality for neurorehabilitation: insights from 3 European clinics. PM&R **10**(9), S198–S206 (2018)
10. Pazzaglia, C., et al.: Comparison of virtual reality rehabilitation and conventional rehabilitation in Parkinson's disease: a randomised controlled trial. Physiotherapy **106**, 36–42 (2020)
11. Severiano, M.I.R., Zeigelboim, B.S., Teive, H.A.G., Santos, G.J.B., Fonseca, V.R.: Effect of virtual reality in Parkinson's disease: a prospective observational study. Arq. Neuropsiquiatr. **76**, 78–84 (2018)
12. Statista Company: https://www.statista.com/study/29689/virtual-reality-vr-statista-dossier/ (January 2021)
13. Turner, T.H., Atkins, A., Keefe, R.S.: Virtual reality functional capacity assessment tool (VRFCAT-SL) in Parkinson's disease. J. Parkinson's Dis. (Preprint), 1–9 (2021)
14. Wang, B., Shen, M., Wang, Y.X., He, Z.W., Chi, S.Q., Yang, Z.H.: Effect of virtual reality on balance and gait ability in patients with Parkinson's disease: a systematic review and meta-analysis. Clin. Rehabil. **33**(7), 1130–1138 (2019)