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PATIENT FACING SYSTEMS

A Kinect-Based System for Lower Limb Rehabilitation in Parkinson's Disease Patients: a Pilot Study

Guillermo Palacios-Navarro [1,3,4] · **Iván García-Magariño** [2] · **Pedro Ramos-Lorente** [1]

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Abstract This work brings together the emerging virtual reality techniques and the natural user interfaces to offer new possibilities in the field of rehabilitation. We have designed a rehabilitation game based on a low cost device (Microsoft Kinect™) connected to a personal computer. It provides patients having Parkinson's Disease (PD) with a motivating way to perform several motor rehabilitation exercises to improve their rehabilitation. The experiment was tested on seven Parkinson's Disease patients and results demonstrated significant improvements in completion time score and in the 10 Meters Walk Test score. Nevertheless, additional research is needed to determine if this type of training has a long-term impact. Both the device and protocol were well accepted by subjects, being safe and easy to use. We conclude that our work provides a simple and suitable tool resulting in a more enriching rehabilitation process where motivation is highly encouraged in PD patients. Feedback coming from participants corroborate the hypothesis that the system can be applied not only in clinical rehabilitation centers but at home.

Keywords Parkinson's disease · Microsoft Kinect · Rehabilitation

Introduction

Parkinson disease (PD) is a chronic neurodegenerative disease. This manifests itself as a series of debilitating motor and non-motor symptoms having a significant impact on activities of daily living (ADL). Nowadays, approximately four million people worldwide suffer from PD, with an average of 1 out of 500 people. It is estimated that over 1,150,000 people aged over 65 in Europe are affected by PD [1].

The main disorders of PD patients are: postural control, disorders in the balance, and a high percentage of risk of falls [2], which reduce their quality of life. This kind of disorders originates a high cost in worldwide health systems and even a high risk of mortality [3]. Apart from the disorders of postural control, PD patients also present other important deficits associated with their pathology: muscular inflexibility, injuries in visual-spatial tasks [4], fear to possible falls, loss of confidence, quakes, and mobility reduction to perform all ADL [5], tremor, bradykinesia, rigidity and postural instability [6]. Consequently, a detriment (physical and cognitive) is generated [7].

Several sources [8, 9] stated that patient interest in performing repetitive tasks involved in traditional treatments is an important drawback in the way of rehabilitation. Indeed, rehabilitation is by its nature repetitive, and repetition tends to "decouple" the mind, and reduce patient's motivation [10]. To overcome this monotony in the performance of tasks, technological advances have been gradually incorporated aimed at

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✉ Guillermo Palacios-Navarro
guillermo.palacios@unizar.es

Iván García-Magariño
Ivangmg@unizar.es

Pedro Ramos-Lorente
pramos@unizar.es

[1] Department of Electronic Engineering and Communications, University of Zaragoza, Teruel, Spain

[2] Department of Computer Science and Engineering of Systems, University of Zaragoza, Teruel, Spain

[3] Departamento de Eléctrica y Electrónica, Universidad de las Fuerzas Armadas ESPE, Sangolquí, Ecuador

[4] Prometeo Project Researcher (SENESCYT), Quito, Ecuador

improving people quality of living. The application of virtual reality technology for the rehabilitation of cognitive and motor deficits has been growing in the last decade and stroke patients have been one of the main target populations for these new rehabilitation methods [8].

Another type of technological elements for Virtual Rehabilitation (VR) deals with the generated tools in augmented reality [11]. Milgram and Kishino [12] defined augmented reality as a variation of the virtual reality, which is based on an overlapping of information into the real world. In short, augmented reality supplements the real world and does not replace it completely. These tools are aimed at getting rehabilitation processes "at home", reducing in this way healthcare costs. We find some alternatives to high costs in the rehabilitation process in Burke et al. [13] where the used system for upper limb stroke rehabilitation is based on the use of a WebCam, and games are controlled by the patient moving his or her hands.

Tools focused on re-education of balance in sit-to-stand (standing balance) have recently emerged. They consist of hardware systems, generally low-cost systems, and having an easy integration in the daily clinical routine. To obtain these goals (low-cost and easy integration), the current trend deals with the use of interfaces originally designed for game consoles, such us the Nintendo WBB [14–19] or the Microsoft Kinect™ [20–22] as well as devices such us Tablet PCs [23].

Our proposal deals with the accomplishment of an application based on augmented reality and the low cost natural user interface Microsoft Kinect™. The kinect is a non-invasive device allowing movement data to be captured easily without the use of sensors or markers.

Kinect has been widely used in the field of rehabilitation. Some studies have tested feasibility of using this device with PD patients. Sooklak et al. [24] explored the possibility of using the kinect in clinical settings for detection of Parkinson's postural, flapping, and voice tremors showing a great deal of feasibility. Geman [25] also used the kinect sensor to extract tremor and gait information from PD patients. Gait analysis has also been performed by Rocha et al. [26] in order to discriminate between non-PD and PD subjects, as well as between the states (stimulator ON and OFF). Pompeu et al. [27] used a commercial game to engage the player in several games exploiting full body motion.

Galna et al. [28] designed an experiment focused on dynamic postural control training. We find some other examples for gait features detection and assessment in [29–31].

We have designed an exercise protocol that relies on body leg reaching movements with different amplitudes and same direction, to induce subjects to increase their movement speed and their sensitivity to movement amplitude. The patient is introduced inside the video game and allowing leg lateral movements to reach and squash a series of moles that appear on the screen. The patient sees him/her self in the game. At the same time, statistics relating to every single game session are provided in order that both patient and clinical staff follow the development of the experience and the advances so far done. The exercise can be adapted to the individual's degree of impairment.

Material and methods

Experimental set-up

The designed system integrates different hardware systems and the software for connection and interaction (Fig. 1). The system consists of a series of screens or displays that fulfill general usability criteria such as learning, comprehension, operational capacity and attractiveness for the end user. It has the following software and hardware requirements:

> Software requirements: The application can be run in systems having the following components: Microsoft Kinect™ SDK v1.0: Official Microsoft Kinect™ driver, Microsoft Framework 4, Windows 7 Operating System, MySQL Database.
>
> Hardware requirements: The minimum system hardware requirements are the following: Microsoft Kinect™ device, 2 GBytes RAM Memory, Graphic Card compatible with DirectX 9 and a processor Intel Pentium 4 3.0 GHz.

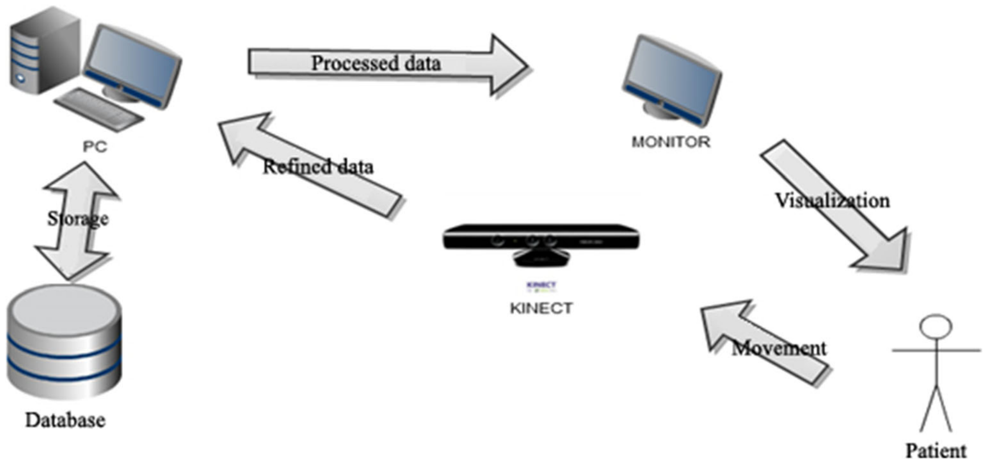
The standard IEEE Recommended Practice for Software Requirements Specifications (IEEE 830–1998) [32] has been taken into account throughout the development of the application.

According to Fig. 1, firstly, the patient performs gestures and movements that are captured by the Microsoft Kinect™. It processes and sends them to the computer. At the same time, the computer runs the application to process the data and then display them on a monitor. In this way, the patient can see his/her movements. Once the game finishes, the system will store results in the database.

The user interface consists of a series of screens or displays that fulfill general usability criteria such as learning, comprehension, operational capacity and attractiveness for the final user. Among others, we can cite the following ones:

- Initial screen: It allows to choice the patient who will do the game.
- Main menu: It allows the access to configuration, to the game or quitting the application.
- Configuration screen: It enables the configuration of parameters such us session duration, number of games, time between games and maximum exercise time.
- Game screen: There is one screen for each game.
- Statistics screen: It shows the final results grouping them into categories.

Fig. 1 System operating schema



The following figures show some of the features of the application.

Figure 2 shows the configuration screen, where the user defines the configuration parameters and after that, the user can do the exercises. The user can display statistics after finishing the game. Finally, Fig. 3 shows the mole appearing from one side of the screen. The subject interacts with the system by stepping moles that appear from both sides (left and right). Subjects were required to stand in front of the screen within 2 meters distance.

Task

The proposed exercise protocol involved lateral leg movements. While standing, the subjects were required to reach one of the two moles, which were presented in random order, either to the right or to the left of the subject (always aligned in the same horizontal line). The movement was considered terminated when the leg first entered the target (mole). Target positions were defined in terms of a subject-centered reference frame. The subject has to return to the central point of the screen to be ready for the next mole to appear. This time is high enough to facilitate this back movement (it can be modified if necessary).

We can see (Fig. 4) that the existing interaction between patient and application is formed by the sequence of actions that composes a rehabilitation session. The main stages in this process are: 1) the physiotherapist (or caregiver) has to select the patient in the active session, 2) configuration of parameters will be established subsequently, according to the degree of difficulty; aimed at obtaining a better adherence between patient and as well as at increasing patient motivation when doing the pre-established virtual movements, 3) the patient performs the motor virtual session, 4) finally, the patient will be able to see obtained results to check the reached progression. This option is totally advisable not only for the patient, but for the physiotherapist (or caregiver), since it provides a visual feedback according to the rehabilitation process.

Fig. 2 Screenshot of the configuration interface

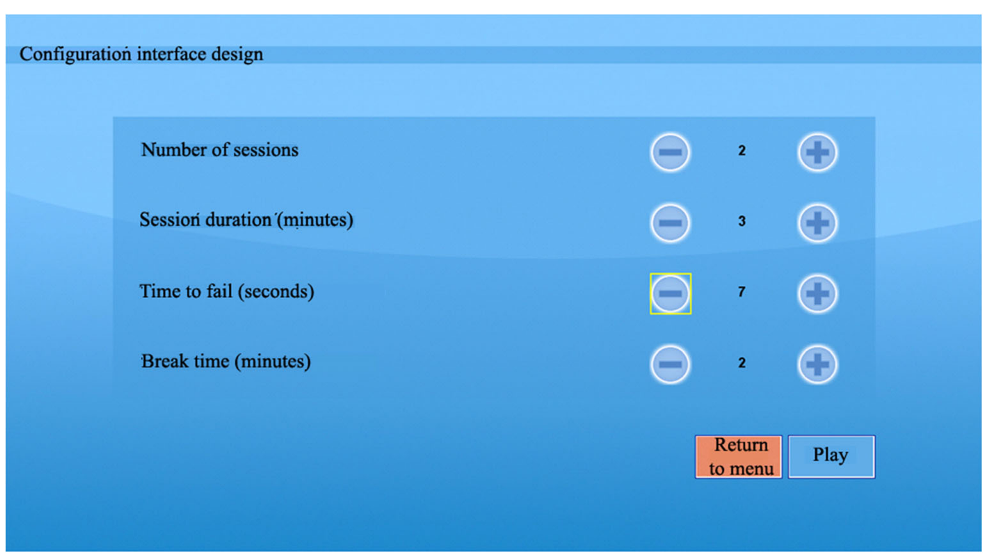


Fig. 3 Screenshot of the game

Exercise protocol

The programme was performed with a 5 week training period (10 h of treatment, 4 sessions per week). Although the system provides different levels of difficulty, an intermediate and not very demanding level was established in order to perform the exercise. Each training session consisted of 30 min, and was organized into epochs, each one corresponding to 40 repetitions of the target.

Time between epochs was at least 3 min. That is to say, the subject should wait for 3 min before beginning with the next epoch.

Patient safety when doing exercises should be taken into account, because they are in danger of a re-injury whenever the exercise has been not properly designed (e.g., leading the patient to over-exercise). In our case, in spite of the fact that the exercise is simple enough, the patient is always assisted by a caregiver while doing virtual rehabilitation exercises.

Subjects

The study involved a total of 7 subjects with idiopathic PD (4 males, 3 females). They also had no experience in testing virtual environments focused on Virtual Motor Rehabilitation (VMR).

The inclusion criteria were subjects having intact cognition (Mini-Mental State Examination MMSE [33] score greater than 24), with no uncontrolled chronic diseases and having no experience in balance or gait training. The exclusion criteria were patients with a history of other neurological diseases affecting postural stability, a history of falls or clinical instability as well as patient refusal.

The age of the seven subjects was 66.8±3.5 (range 62–72). Before the start of the experience protocol, the subjects' performance with the 10-Meters-Walk test (10MWT) [34] was 12±6 (range 6–20 s). In this test, subjects were instructed to walk as fast as possible. All the subjects were taking medications at the time of testing and were in their 'ON' phase during training.

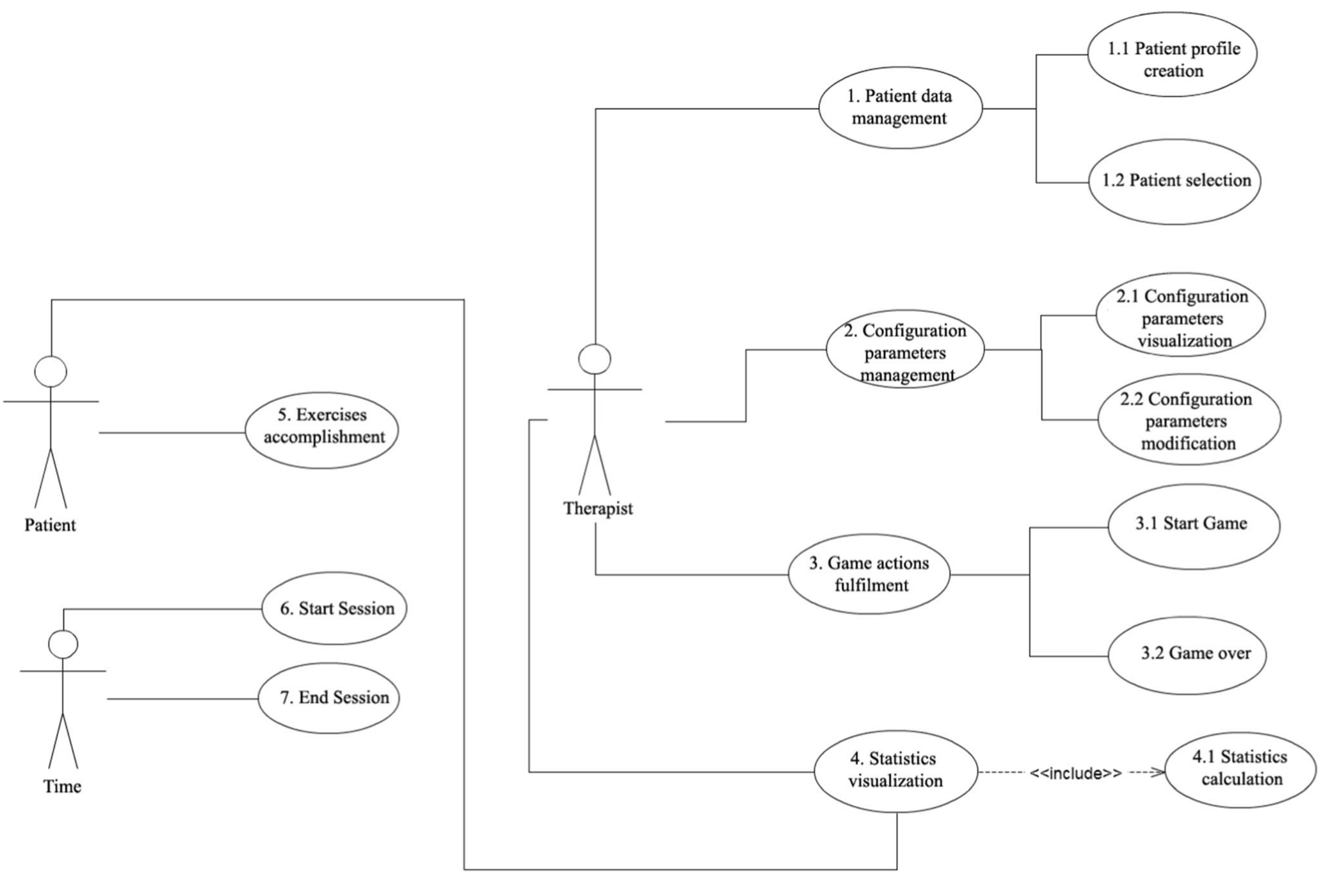


Fig. 4 Diagram of use cases

The research conforms to the ethical standards laid down in the 1964 Declaration of Helsinki [35] that protects research subjects. Informed consent was obtained from all the participants. They were also informed that they could leave the study at any time without the necessity of giving any explanation. Table 1 shows subjects' demographic and clinical information.

Data analysis

PD patients should do rehab exercises involving several parts of their bodies. They are focused on the improvement of balance, increase of mobility as well as coordination. They include mobilization and general exercises for the main parts of the body. We have focused our analysis on legs exercises, aimed at improving both movement coordination and balance.

The developed tool was first tested with healthy subjects. A total of 7 healthy subjects were recruited for the experiment. The inclusion criteria were subjects with no experience in balance or gait training. They also had no experience in testing virtual environments focused on Virtual Motor Rehabilitation (VMR). Informed consent was obtained from all participants.

Fitts' law The experiment performed with healthy subjects served us to demonstrate how it matched Fitts' Law [36] by showing different moments in the rehabilitation process for a single subject. Fitts' Law (Eq. 1) describes a linear relationship between the time (T) needed to move from a start to a target location and the properties these locations possess, such as the size of the target (W) and the distance between the start and the target (D). The logarithmic term of this relationship is called "Index of Difficulty" (ID). Equation 1 shows the Shannon formulation of Fitts' Law, which has been shown to fit measured data of low IDs better compared to the original formulation [37]. The relationship between movement time (MT) and ID can be obtained by measuring movement times for a number of different IDs and performing a linear regression on the acquired data. This will yield values for intercept (a) and slope (b), which are both distinctive for a person's or patient's current reaching motion and the input device that was used.

Table 1 Subjects' demographic and clinical information

Subject	Sex	Age [y]	10MWT [s]
S1	M	68	6.7
S2	M	65	5.9
S3	F	70	18.2
S4	M	72	20.1
S5	F	64	12.3
S6	M	67	10.5
S7	F	62	7.3
Mean ± SD		67±3	12±6

M male, *F* female, *10MWT* 10 Meter Walk Test

$$T = a + b\log_2\left(1 + \frac{D}{W}\right) \tag{1}$$

Fitt's law is a very robust and quantitative law that can be applied to human-computer interaction research and design. A great number of studies have been conducted to verify and apply Fitts' law [38–40]. If we pay attention to the obtained rehabilitation results (below), we will see that the logarithmic relationship between movement time and tangential width of target in a tapping task also exists between movement time and normal width of the target in our "mole crushing" task within the application.

According to the established premises above, we show representative results from our experiment. These results coming from a healthy subject at the beginning of his sessions (session 3), and at the end (session 20). We can observe in Figs. 5 and 6 the MT-ID relationship graph as well as the regression line, together with some parameters such us (maximum level reached and correlation term). Since lower-extremity rehabilitation of Parkinson patients is concerned with the reacquisition of reaching motions, Fitts' Law allows to assess the current quality of a patient's movement, thus yielding information about his/her capabilities. This has been already shown in [40]. So, the proposed game seems to be suitable for PD patient rehabilitation.

Completion time For each movement we calculated the Completion Time (CT), which was defined as the time interval between the 'mole appearance' in the screen and the 'mole crushing' done by the subject. For that purpose, the Mole application was adjusted in order to discard the performance rate, that is to say, every subject must try to crush the mole no matter the time it consumes. It is supposed that the performance rate will be 100 % in almost all the cases. We have chosen for this experience an index of difficulty (ID) close to 3, which is not very demanding. With training, subjects are expected to improve their performance. Therefore, they are supposed to achieve the target faster and consequently decreasing the completion times.

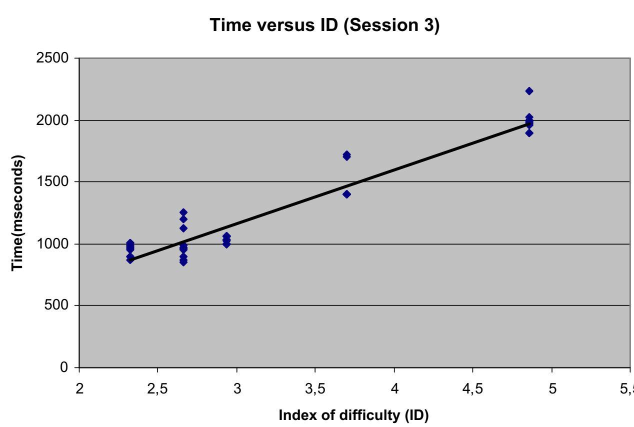


Fig. 5 Scatter-Plot graph of the MT-ID relationship and regression line (3rd session). Maximum level: 3/5. Correlation term: 0.865

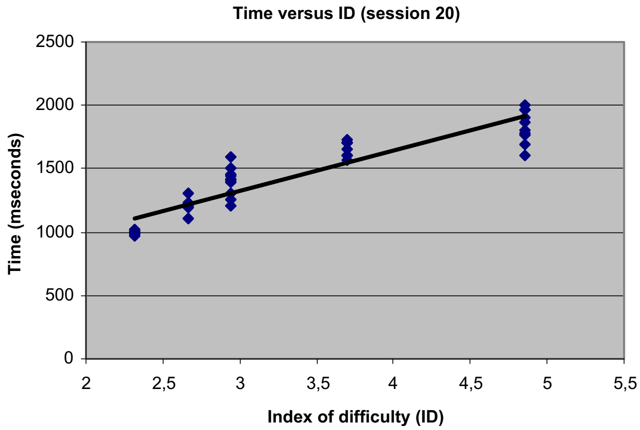


Fig. 6 Scatter-Plot graph of the MT-ID relationship and regression line (20th session). Maximum level: 5/5, Performance rate: 96 %, Correlation term: 0.93

Table 2 10 MWT test before and after training

	10 MWT (seconds)	
Subject	Before	After
S1	6.7	6.1
S2	5.9	4.6
S3	18.2	14.6
S4	20.1	18.5
S5	12.3	10.1
S6	10.5	8.8
S7	7.3	5.9
Mean ± SD	12±6	10±5

Results

The exercise protocol was well accepted by all the subjects. Figure 7 shows the box graph for the Completion Time (CT), or time to fulfill the task of crushing a mole before and after training, respectively. Rehabilitation session 20 was the last session. Across sessions, subjects significantly decreased the completion time (p=0.002; paired samples t-test).

In order to assess whether the training protocol resulted in modifications of the subjects' degree of impairment, we performed the 10MWT before the start and at the end of the training protocol. Table 2 shows the 10MWT scores, respectively, before and after training, was 12±6 s (range 6–20 s) and 10±5 s (range 5–19 s). A comparison in the 10MWT scores before and after training has been performed using a paired sample t-test. We found significant differences from the statistical point of view (p=0.002). The statistical software used has been the Statistical Package for Social Sciences (SPSS®) version 15 for Windows®. A significance level of p≤0.05 has been adopted. Figure 8 shows the 10 MWT results at the beginning and at the end of the training, respectively.

Discussion

The first aim of this study was to create a video game for people with PD. Video games for rehabilitation may provide clinicians with an effective therapeutic tool to improve rehabilitation of motor function [20] in people with neuropathies such as traumatic brain injury [41] or stroke [18]. However, it is important that the rehabilitation games are designed within the context of the specific rehabilitation needs and capabilities of the target population [42].

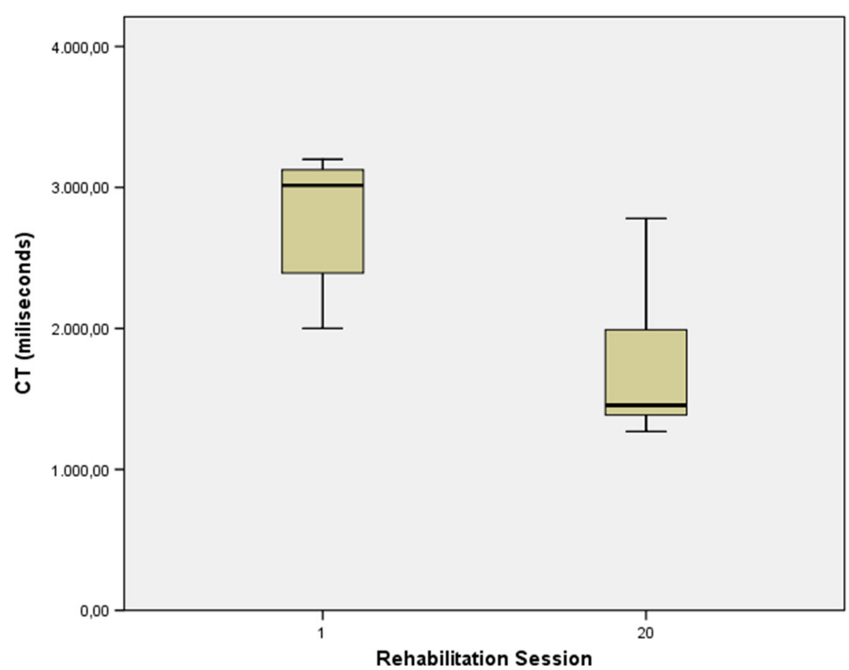


Fig. 7 Box plot showing Completion Time (CT) versus rehabilitation session

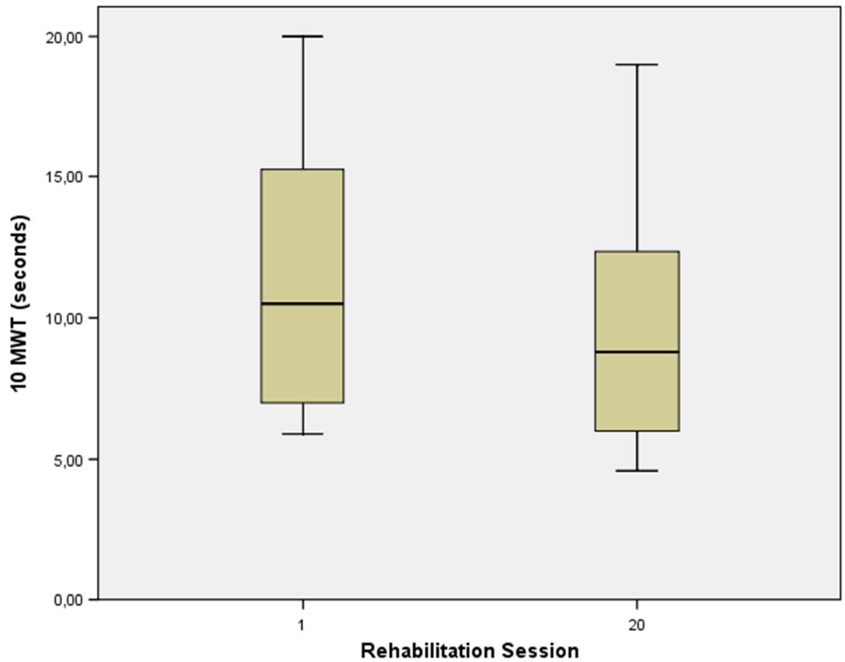


Fig. 8 Box plot showing 10 MWT results at the beginning and at the end of the training, respectively

The rehabilitation needs and capabilities of people with PD vary greatly between people and throughout the progression of the disease. According to Mendes et al. [43], one important consideration is that the games for people with PD should not be made too difficult, in terms of their pace or cognitive complexity.

In line with this assumption, the game was designed to be as simple as possible not only from the motor but from the cognitive point of view. Due to our purpose of assess motor functions, the cognitive aspect had to be as simple as possible. The exercise protocol designed focused on leg amplitude movements, aimed at increasing movement speed through the repeated practice. All the participants successfully completed the trial and they enjoyed the game and showed a great deal of commitment in the sessions.

The programme was performed with a 5 week training period (10 h of treatment, 4 sessions per week) with positive results but it would be interesting to study a longer period (12 weeks). We observed general improvements in completion time and in the 10 MWT clinical scale. This is line with Pompeu et al. work [27] that showed that 7 patients with PD improved their g-minute walk test after a Kinect-based training protocol consisting of fourteen 60-min sessions during 4 1/2 weeks.

Likewise, Ebersbach et al. [44] showed that a total of 16 h or training (1 h treatment session) during 4 weeks resulted in a significant reduction of the UPRDS-III score. In a recent work [45] a lower reduction was observed after a shorter duration (2 weeks) version of the same LSVT protocol (a total of 8 h of treatment). Our findings are consistent with the abovementioned ones taking into account that our training protocol duration is slightly higher than [45] but lower than [27] and [44].

Feasibility

Overall, the feedback from the pilot study was positive. Patients' feedback was assess by means of the comments written by caregivers taking into account the experiences of patients. Nevertheless, participants provide us with constructive feedback to help us identify issues where the game can be improved. We only provide a visual feedback to show partial results. We provide neither feedback nor cueing (auditory) on task performance to explicitly stimulate subjects' motivation. For example, the inclusion of cueing (auditory or visual) to provoke higher motivation could be an issue to be taken into account in future developments for people with PD. In this regard, despite the fact that we are in favour of natural interfaces and low cost devices for rehabilitation processes, the use of complex task practice rather than repetition of a simple movement has been shown to produce a more pronounced alteration in the neural circuitry suggesting cortical reorganization [46]. A common feature of these studies deals with the introduction of enhanced sensory feedback (auditory, visual or somatosensory) cues to provide augmented feedback about performance. Motor learning is enhanced by external cueing [47] whilst clinical studies have shown that externally cued practice over more extended periods (3–6 weeks) leads to significant benefits for gait and balance [48–50] and is more effective than interventions that do not use augmented feedback [44, 51].

Some other studies have considered the introduction of virtual cueing and wearable devices such as Virtual Reality Glasses (VRG), reporting beneficial effects in motor rehabilitation [52–55]. Espay [52] provided gait velocity, stride length, and cadence to demonstrate the effectiveness of interventions with VRG using closed-loop sensory feedback.

Through an at-home training programme, patients with PD were able to improve gait while decreasing freezing. Nearly 70 % of the subjects showed residual improvements of at least 20 % in velocity, stride length, or both. The closed-loop system designed by Baram et al. [56] responds to the patient's own motion and helps him regulate his gait. The measured parameters were: the time to complete the track and the number of steps for each path, speed and stride length. Performance of PD patients using a closed-loop display improved (higher speed, longer stride) by about 30 % on average.

All these studies represent a novel area of development with a great potential in motor rehabilitation. As far as outcome measures to assess the motor improvements in PD patients concerned, Griffin et al. [54] also used the task completion time, as well as some others like velocity, cadence and stride length [52, 54, 56].

Safety

All the participants felt safe whilst playing the game and there were no adverse events during any of the sessions. Galna et al. [28] used Kinect for retraining functions in patients with Parkinson's disease (PD) and concluded that Kinect-based games are, in general, safe and feasible for PD rehabilitation but interventions should be carefully reviewed for safety. In our experiment, a caregiver or a physiotherapist always attended the sessions, just in case of some participants had some difficulties during the stepping tasks. The level of difficulty of the game was set up in such a way that no time pressure was present. Participants in this study enjoyed playing the game and also improved with practice.

Limitations

This pilot study did not include a control group and evaluated an intervention with a small group. The absence of follow-up evaluation should also be a limitation of this study. Therefore, residual effects have not been considered. Although the small number of subjects participating in the experiment shows promising results, further research with more subjects as well as the analyses of more clinical test would be desirable to generalize our findings to the PD population. It could be also interesting to promote transfer of the improved performance to activities of daily living (ADL). Furthermore, the comparison to traditional rehabilitation programs could give us some more power of generalization to the broader population of people with PD.

Conclusions

With this experiment, we have explored the potential of the Microsoft Kinect in the rehabilitation of PD patients. The mail goal deals with the mitigation of specific symptoms such as bradykinesia in these patients. Although preliminary results show improvements in completion time and in the 10 WMT, we can not state that it is due to familiarization with the task. So this fact should be addressed in future developments by implementing some other motor activities. In this regard, quality characteristics in IEEE 830 are generally applicable and valuable but there is a lack of customization to specific quality model for this type of systems, so future actions should explore the possibility of creating a domain-specific quality model [57] as it has been already done in the case of [58].

Furthermore, as a future work, we could compare the effects of training with a baseline (e.g., PD subjects ON vs. OFF medication, or healthy subjects) or even clustering subjects depending on their physical and cognitive capabilities.

The introduction of low cost devices together with the design of video game-based applications in rehabilitation processes makes them much more attractive and enjoyable than traditional methods. In contrast to some applications suggesting the necessity of robots or complex monitoring systems in order to control movements of parts of the body, the developed system is clearly affordable not only in rehabilitation centres but in at home environments. In this regard, we have to take into account that PD patients could exhibit balance disorders in most cases. For that reason, in order to prevent the risk of falls, a person (caregiver or relative) should stand by the patient side.

With the development of this experiment, we also wanted to explore the potential of natural interfaces in rehabilitation processes. Subjects using this kind of interfaces do not have to wear sensors or markers, so they are more appealing and make their use more intuitive, comfortable and enjoyable. They are becoming more and more popular in virtual rehabilitation not only in conjunction with off-the-shelf video games but in conjunction with ad-hoc exercises targeted to specific types of impairment. Results coming from this pilot study suggest that a home-based training programme using Kinect could lead to improved static and dynamic balance, global mobility and functional abilities of PD-affected persons. Nevertheless, further studies are needed in order to generalize these results.

For these reasons, we are convinced that this is a first step toward a true virtual rehabilitation. The gradual acceptance of this type of rehabilitation is undoubtedly a great challenge for the forthcoming years in the field of rehabilitation.

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Competing interest The authors declare that they have no competing interests.

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