

# Learning of a postural control task in a virtual environment with Parkinson's disease individuals

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## HIGHLIGHTS

- Individuals with mild and moderate PD can learn tasks with a high demand of postural control, retaining them even with longer retention intervals.
- The skill learning in mild and moderate PD led to an improvement in cognitive functions, specifically in memory.
- The skill learning mild and moderate PD led to an improvement reactive aspect of postural control.

## ABBREVIATIONS

|         |                                                 |
|---------|-------------------------------------------------|
| APA's   | Anticipatory postural adjustments               |
| BESTest | Balance Evaluation System Test                  |
| CG      | Control Group                                   |
| CR      | Knowledge of results                            |
| EG      | Experimental Group                              |
| ES      | Effect size                                     |
| MoCA    | Montreal Cognitive Assessment                   |
| PD      | Parkinson's disease                             |
| UPDRS   | Unified Scale Evaluation of Parkinson's Disease |

## PUBLICATION DATA

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**BACKGROUND:** Recent studies have shown individuals with Parkinson's disease (PD) are able to learn tasks with postural control demand, however, they need more practice, more sensory information, and extrinsic feedback for this improvement. These aspects could be provided by task performance on virtual environment. In addition, the retention interval found in these studies was short (hours/days). Retention interval is considered a critical factor for motor learning, especially for individuals with a neurodegenerative disease such as PD.

**AIM:** 1) To investigate the extent to which the learning of tasks involving a high demand for postural control is impacted in individuals with PD, and 2) To determine the impact of the learning process on both cognition and postural control.

**METHOD:** The Experimental Group (EG) comprised 13 participants with idiopathic PD [64.28±6.35 years; Hoehn and Yahr modified scale = 1.0-3.0] and the Control Group (CG) comprises 14 healthy elderly [69.71±5.91 years]. Participants took part in 13 one-hour sessions (2x/week for 7 weeks), which involved four Kinect system games, with high postural and cognitive demands. The first session was considered pre-test, and the last session as post-test. The short-term retention test was performed one week after the post-test, whereas the long-term retention test was performed one month after the post-test. Global cognition and postural control were assessed at 3 time points: baseline, post-test and at one month after the post-test.

**RESULTS:** Individuals with PD learned the tasks with a high demand of postural control and demonstrated both short and long-term retention. The skill learning of the four tasks led to an improvement in cognitive functions specifically in memory. There was an improvement of reactive aspects of postural control in the elderly and with the individuals with PD, also better gait stability in the elderly.

**CONCLUSION:** Despite the degeneration in striatum, responsible of consolidation of motor learning, individuals with PD are able to learn motor skills with a high demand for postural control, retaining them in the long term.

**KEYWORDS:** Parkinson's disease | Postural control | Motor learning | Virtual reality

## INTRODUCTION

Postural instability is one of the most limiting symptoms in Parkinson's disease (PD) <sup>1</sup>, which appears in the early stages of the disease <sup>1</sup>. With the disease progression, postural control is affected by both cognitive and motor impairment <sup>2</sup>, due to the complex interaction of these systems <sup>3</sup>. The main changes in postural control found in PD are deficits in anticipatory postural adjustments with delayed muscle contraction <sup>4</sup>, reactive responses <sup>5</sup> dynamic postural control <sup>5</sup>, anteriority of the center of mass <sup>6</sup> and reduced limits of stability <sup>7</sup>. Individuals with PD have a lack of flexibility in the presence of environmental imbalances, in other words, they have difficulty

making postural control adjustments to meet the demands of the environment, which increases the risk of falls<sup>8</sup>, and reliance on visual information to maintain postural stability<sup>9</sup>. Postural control is also impacted by both inadequate prioritization strategy in secondary task and the focus of attention while performing dual tasks<sup>10</sup>.

Changes in postural control significantly impact the motor behavior of individuals with PD. As individuals with PD present alterations in postural control, it is unclear whether the learning of tasks with a high demand for postural control could be impacted, since motor learning is task-specific<sup>11</sup>. Furthermore, motor learning relies heavily on subcortical structures, including the basal ganglia<sup>12,13</sup>, which are affected by PD<sup>12,13</sup>, especially in the consolidation of the learning motor act<sup>14</sup>. However, some studies have already shown that individuals with PD are able to learn tasks related to postural control<sup>15-18</sup>.

The interval between an acquisition and a retention test is a critical factor for learning new skills<sup>19</sup>. As PD is a neurodegenerative disease, the interval between the acquisition and the retention test needs to be addressed in this population. In the literature, a short interval between acquisition and retention was used one hour<sup>18</sup> to one week<sup>20</sup>.

The use of additional sensory information as targets, visual feedback, and knowledge of results (CR) is another important factor to optimize motor learning in individuals with PD<sup>21,22</sup>. Evidence supports the use of additional sensory information to achieve better performance and the maintenance improved performance immediately after sensory information is removed<sup>14,22,23</sup>. Virtual reality environments can enhance motor learning process in individuals with PD<sup>24</sup>, virtual environments offers the opportunity to provide immediate extrinsic feedback (i.e., knowledge of the performance and results)<sup>22,24</sup>, repetition of complex tasks<sup>25</sup>, visual and auditory stimuli used as external cues<sup>25</sup> and can keep the learner motivated<sup>22,24</sup>, which are essential for motor learning<sup>14</sup>.

Given the importance of the postural control impairment during the progression of the disease, it becomes relevant to determine if, from the practice of tasks involving high demands for postural control in a controlled environment, individuals with DP can maintain an improved performance for an extended period. It also remains unclear if the adaptability of performance can generate changes in postural control and cognition. The study aims to determine the extent to which PD impacts motor learning through short and long-term retention tests. We also aim to investigate the impact of practice in virtual reality on postural control and cognition in individuals with PD. We hypothesized that individuals with PD will 1) have detrimental performance compared to neurologically healthy elderly during the acquisition phase<sup>26</sup>, 2) learn the four selected tasks, demonstrated through improved performance in the short and long-term retention tests<sup>19</sup>, 3) learn the skills in a virtual reality environment, which will positively impact the postural control and cognition of individuals with PD<sup>13</sup>, as well as neurologically healthy elderly.

## METHODS

The study was approved by the Ethics and Research Committee of the School of Physical Education and Sport of the University of São Paulo (CAAE: 44795315.8.1001.5391). This study is part of a larger randomized clinical trial (registration: RBR-27kqv5).

### Inclusion and exclusion criteria

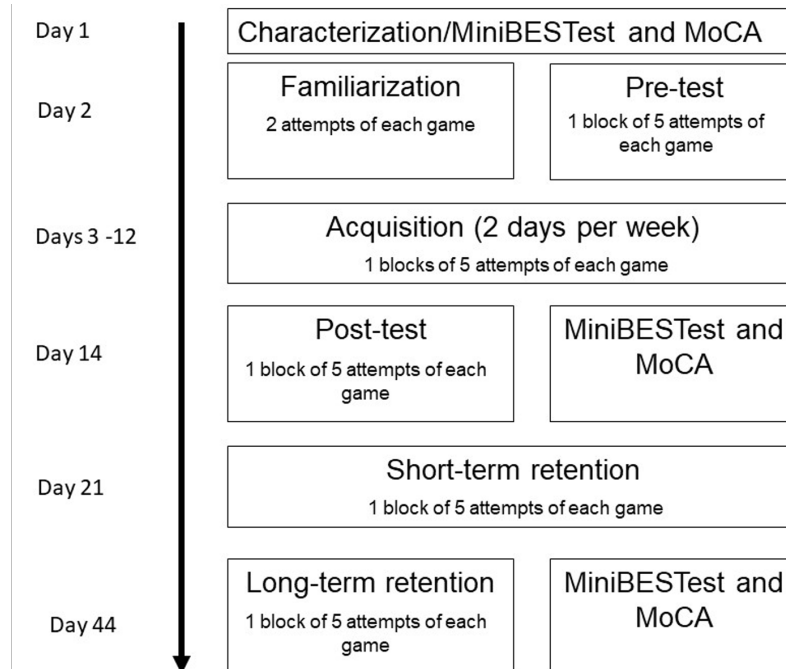
For the experimental group (EG), we recruited individuals aged between 60 to 80 years old with idiopathic PD, modified Hoehn and Yahr scale 1-3, and treated with levodopa. Participants were included if they had a score < 28 on the Mini Balance Evaluation System Test (MiniBESTest)<sup>27</sup>. For the control group (CG), non-disabled aged-matched elderly were recruited.

For both groups, participants were included if they had: normal or corrected visual acuity; good auditory acuity; at least 3 years of education; no previous experience with the game Kinect Adventures!®; and provided informed consent.

The exclusion criteria were no other detectable neurological, cardiorespiratory, or orthopedic diseases; no signs of dementia (score of >26/30 on the Montreal Cognitive Assessment (MoCA))<sup>28</sup>. For the EG, participants were excluded if they were part of a rehabilitation program within the last six months or if they presented any type of clinical deficits that made it impossible to perform physical exercises in standing positions, i.e., fall occurrences, freezing observed both at the initial evaluation and during the intervention.

### Experimental Design

The experimental design was published in Silva 29 and Figure 1 displays the different phases involved in this design.



**Figure 1.** Experimental design. MiniBESTest: Mini Balance Evaluation System Test; MoCA: Montreal Cognitive Assessment.

The initial assessments were carried out to characterize the sample. Data collected in the EG were age, gender, education, time since diagnosis of PD, medication, motor disease severity assessed with the modified Hoehn and Yahr Scale<sup>30</sup> and the Unified Scale Evaluation of Parkinson's Disease (UPDRS) section III<sup>31</sup>. Individuals in the CG were characterized by age, gender, and education. Both groups performed a postural control evaluation, using the MiniBESTest<sup>27</sup> and a cognition evaluation<sup>28</sup> (Figure 1).

The MiniBESTest is a more concise form of the BESTest (Balance Evaluation System Test). The BESTest, which was designed to evaluate six systems involved in postural control: (1) biomechanical restrictions; (2) verticality and stability limits; (3) anticipatory postural adjustments (APAs); (4) postural responses; (5) sensory orientation and (6) gait stability. MiniBESTest does not include systems (1) and (2) in BESTest. Also, MiniBESTest assess four systems, it consists of 14 tasks scored from 0 to 2 according to the participant's performance, with higher scores indicating better balance. It evaluates, among other items, the base of support, the alignment of the center of pressure, strength and range of motion of the ankle, sitting and standing, functional reach, balance in single-leg stance, gait and performance in the stand-up and walk test in a simple task and dual task<sup>27</sup>.

MoCA - Brazilian version, is a cognitive screening instrument that accesses different domains, such as attention and concentration, executive functions, memory, language, visual-constructive skills, conceptualization, calculation, and orientation<sup>28</sup>.

After the initial evaluation, participants took part in thirteen training sessions using four games from the Kinect Adventure! (Xbox 360, Microsoft, Redmond, CA). Each game is described in the *Task Description* section. Whole-body movements were captured with the Kinect camera. Training sessions were conducted individually in a laboratory setting, under the supervision of an experienced therapist. When needed, participants were offered short rest periods.

The first session consisted of a familiarization period and a pre-test. A researcher provided detailed instructions and demonstrated each game. Each participant practiced two attempts for each game. The researcher offered movement and posture corrections through manual guidance and verbal commands when needed. During the pre-test, participants performed a single block of five attempts for each of the four games. The acquisition phase consisted of eleven one-hour sessions offered twice a week. Each session consisted of varied practice in blocks of four games, with five attempts for each game<sup>32</sup>.

The post-test session comprised the same numbers of blocks as acquisition phase. The post-test session was performed two days after the acquisition phase and included a balance and cognitive evaluation with the MiniBESTest and the MoCA, respectively, for both groups. If the participant missed a practice session in the acquisition phase, the session was rescheduled in the same week to avoid impacting the practice interval between the experimental sessions.

The short-term retention test was administered one week after the post-test, whereas the long-term retention test was performed one month after the post-test. The retention tests involved the practice of each four tasks, using the same conditions as used in the acquisition phase. The MiniBESTest and the MoCA were also administered during the long-term retention testing session.

The study is part of a larger clinical trial, which lasts seven weeks and includes a follow-up assessment one month post-intervention<sup>29,33</sup>. The number of sessions used in this study follows the experimental condition of the clinical trial (14 experimental sessions), where the first session was used as our pre-test and the second to last the post-test and the last session the short-term

retention test (that it was performed once week after the post-test). In addition, in the pilot study, we found that this amount of practice was sufficient to improve performance on the four tasks of participants with PD.

The initial assessment and all practice sessions of EG participants were performed in the ON period of dopaminergic replacement.

### Task Description

The games were selected based on a pilot study<sup>25</sup> to ensure: (a) constant displacement of the participant's center of mass through the movement of the upper limbs; (B) weight transfer between lower limbs; (C) squatting; (D) the slopes of the trunk. The cognitive demands established for the selection of games were: (a) visuospatial attention; (B) change of attention; (C) decision making; (D) rapid reaction time; (E) immediate planning and execution.

We selected the following four games: 20,000 Leaks; Space Pop; Reflex Ridge and River Rush<sup>25,29</sup>. Task descriptions are provided in the supplemental material.

### Data analysis

For all games, the final score was used as the dependent variable (supplemental material). For the MiniBESTest and the MoCA, the total and domains (MiniBESTest domains: APAs, postural adjustments, postural responses, sensory orientation, stability of gait; MoCA domains: visuospatial, naming, attention, language, abstraction, memory and orientation) scores were the dependent variable.

The *a priori* sample size calculation was performed based on a pilot study with three participants. in the EG. The sample size calculation was performed separately for each game on the pre-test and post-test, with a significance level of 5% and test power of 80%.

After performing the calculation for each game, we selected the largest number of participants to obtain the effect. This game was River Rush with 14 participants in each group.

Demographic data and clinical characteristics of participants from both groups were compared using the t-test for independent samples.

Normality tests and homogeneity of variance were performed using the Kolmogorov-Smirnov and Levene test, respectively. Inferential analyses of the pre-test, post-test, and short-term and long-term retention times were performed using the Multiple Comparison Analysis of Variance (4x2). Inferential analyses of the changes in postural control and cognition at the pre-test, post-test, and follow-up times were performed employing the Multiple Comparison Analysis of Variance (3x2), with Tukey post hoc in both conditions. We performed a calculation of the p-value and effect size (ES). The alpha of 0.05 was used as statistical significance.

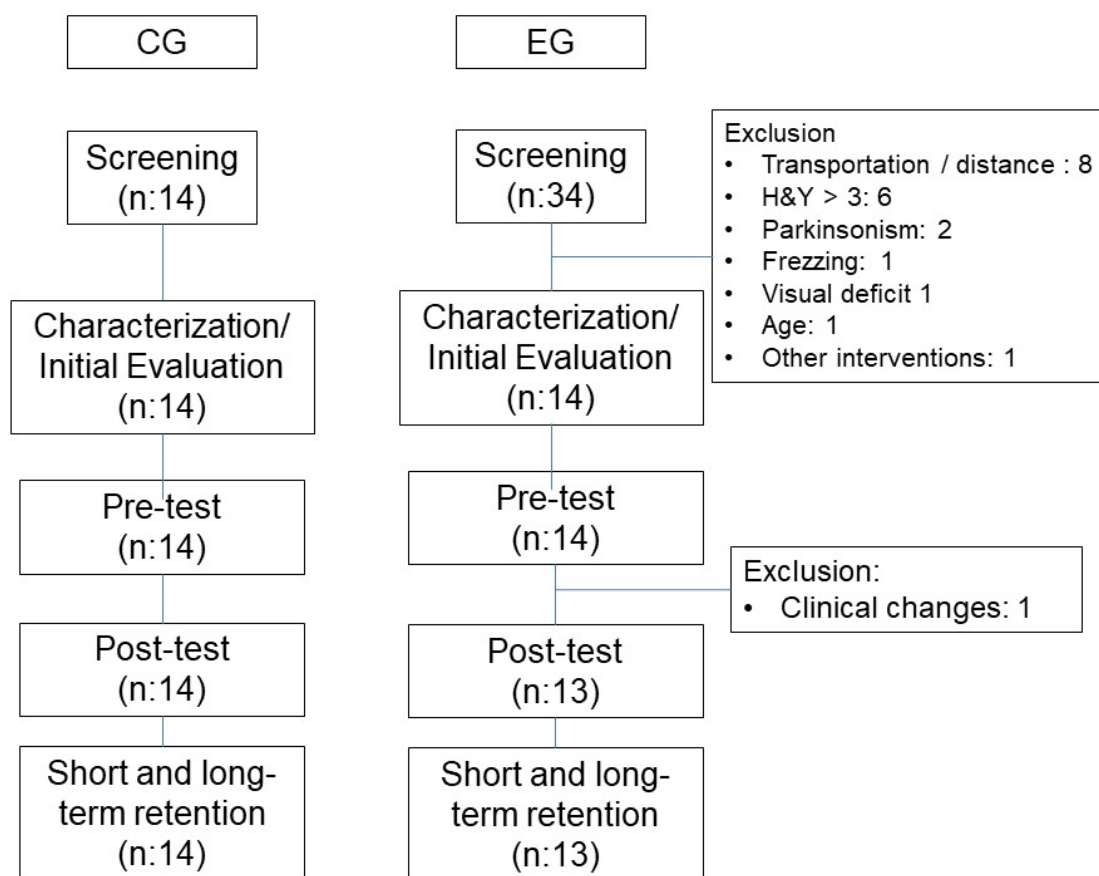
## RESULTS

Fourteen participants in each group took part in this study (Table 1). No participant missed a session during the acquisition phase, however one EG participant did not complete the study due to clinical instability and he was excluded from the analysis (Figure 2). Both groups did not differ, except for postural control.

**Table 1.** Characterization of study participants (Control Group, n=14; Experimental Group, n=13).

|                              | EG           | CG           | p             |
|------------------------------|--------------|--------------|---------------|
| <b>Gender (F/M)</b>          | 4/9          | 10/4         | _____         |
| <b>Age mean (sd)</b>         | 64.28 (6.35) | 69.71 (5.91) | 0.91          |
| <b>Education mean (sd)</b>   | 11.07 (4.61) | 11.57 (2.92) | 0.73          |
| <b>MoCA mean (sd)</b>        | 22.42 (3.41) | 23.64 (3.17) | 0.854         |
| <b>MiniBESTest mean (sd)</b> | 20.78 (6.54) | 27.35 (2.67) | <b>0.032*</b> |
| <b>UPDRS mean (sd)</b>       | 20.5 (8.65)  | _____        | _____         |
|                              | 1: 14.28%;   |              |               |
|                              | 1.5: 14.28%; |              |               |
| <b>H&amp;Y</b>               | 2: 7.14%;    | _____        | _____         |
|                              | 2.5: 21.42%; |              |               |
|                              | 3: 42.85%.   |              |               |

EG: Experimental group; CG: Control group; H&Y: Modified Hoehn & Yahr Scale; MoCA: Montreal Cognitive Assessment; MiniBESTest: Mini Balance Evaluation System Test F: female; M: male; sd: standard deviation; \*:  $p \leq 0.05$ .



**Figure 2.** Study flowchart. CG: control group; EG: experimental group; n: number of participants; H&Y: Modified Hoehn & Yahr Scale.

### Game Learning Analysis

Both groups learned the four games during the acquisition phase, but the EG scored consistently lower scores than the CG for all four games (Figure 3).

Game performance for the four games differed between groups, as the EG always had inferior score to CG (20,000 Leaks:  $p < 0.0001$ ; ES = 0.989; Space Pop:  $p = 0.003$ ; ES = 0.856; Reflex Ridge:  $p = 0.003$ ; ES = 0.893; River Rush:  $p < 0.0001$ ; ES = 0.972), with no interaction effect between the moment and group factors (20,000 Leaks:  $p = 0.411$ ; ES = 0.207; Space Pop:  $p = 0.135$ ; ES = 0.411; Reflex Ridge:  $p = 0.624$ ; ES = 0.124; River Rush:  $p = 0.155$ ; ES = 0.371) (Figure 3).

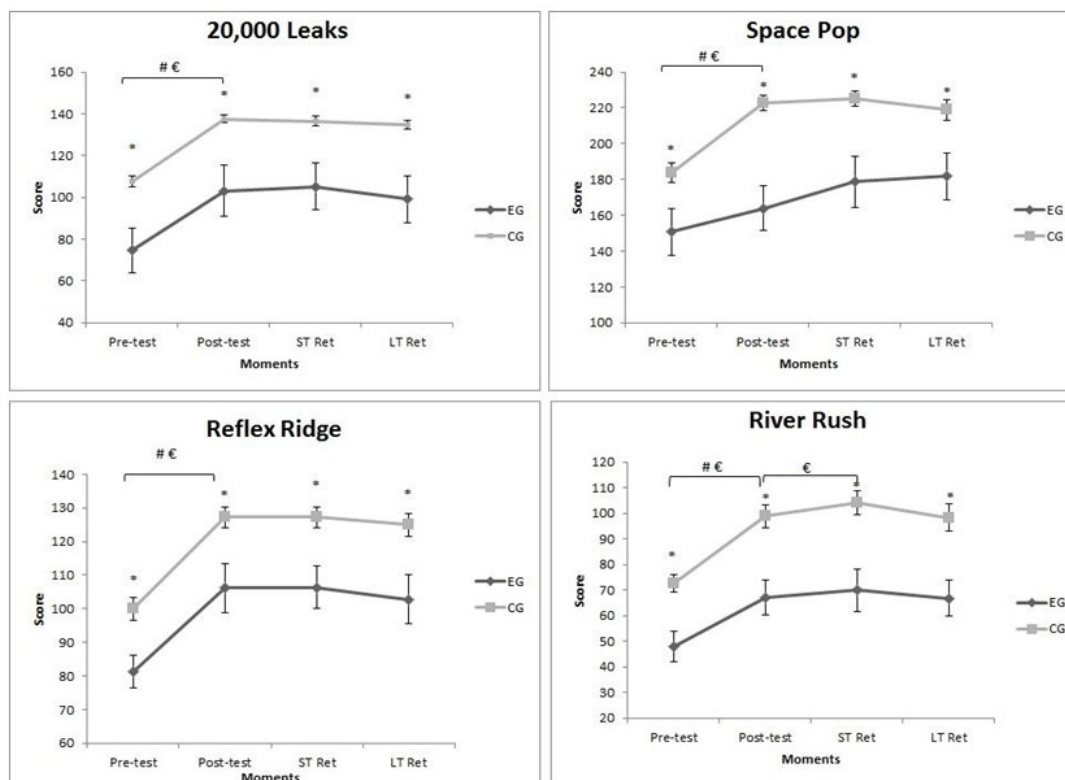
Despite the lower performance of EG compared to CG, in intragroup analysis, there was a significant increase in the performance between the pre-test and post-test in both groups for all games (20,000 Leaks:  $p < 0.0001$ ; ES = 1.000; Space Pop:  $p < 0.0001$ ; ES = 1.000; Reflex Ridge:  $p < 0.0001$ ; ES = 1.000; River Rush:  $p < 0.0001$ ; ES = 1.000), and the post-test performance was maintained for the short and long-term retention tests in all games, except for the CG in the River Rush game between the post-test and the short-term retention ( $p = 0.008$ ; ES = 0.786) (Figure 3).

### Postural control and cognition evaluation

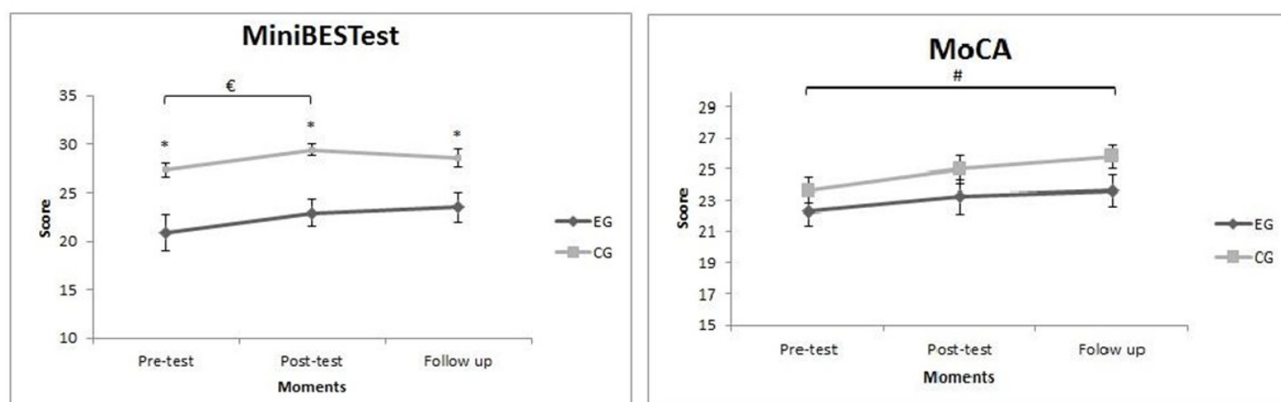
The present study also investigated whether task practice in a virtual reality environment led to changes in postural control and cognition.

For the changes in postural control, both groups differed at all time points in the total MiniBESTest score ( $p = 0.001$ ; ES = 0.954) and in all domains (Table 2), and there was no interaction between time and group factors ( $p = 0.430$ ; ES = 0.189). For the intragroup analysis, there was a difference between the pre-test and post-test ( $p = 0.007$ ; ES = 0.802) only for the CG (Figure 4).

When looking at each domain of the MiniBESTest, there was a difference in the intergroup analysis for all domains. Also, postural responses and stability of the gait domains differed within group (Table 2). In the intragroup analyses, EG presented a statistically significant difference between pre-test and post-test in the Postural Responses domain; and CG showed improvement between pre-test and post-test for the Posture Response and Stability of Gait domains; and there was a significant worsening between the post-test and the follow-up in the Stability of Gait domain.



**Figure 3.** Measures of learning of the practiced games (Control Group - n=14; Experimental Group - n=13). ST Ret CP: Short-term Retention, LT Ret: Long-term Retention, EG: experimental group, CG: control group, \* intergroup difference, #: intragroup difference in EG, €: intragroup difference in CG.  $p \leq 0.05$ .



**Figure 4.** Postural control and cognition evaluation (Control Group - n=14; Experimental Group - n=13). EG: experimental group, CG: control group; \* intergroup difference, €: intragroup difference in CG, #: intragroup difference.  $p \leq 0.05$ .

**Table 2.** Postural control domains measured by the MiniBESTest (Control Group - n=14; Experimental Group - n=13).

|                            |           | Pre-test<br>mean (sd) | Post-test<br>mean (sd) | Follow-up<br>mean (sd) | Intragroup analyses               | Intergroup analyses |
|----------------------------|-----------|-----------------------|------------------------|------------------------|-----------------------------------|---------------------|
| <b>APAs</b>                | <b>EG</b> | 5.69 (1.88)           | 5.92 (1.38)            | 5.92 (1.44)            | p=0.15; ES=0.352                  | p=0.07; ES=0.810    |
|                            | <b>CG</b> | 6.64 (1.27)           | 7.21 (0.97)            | 7.28 (1.20)            |                                   |                     |
| <b>Postural Responses</b>  | <b>EG</b> | 4.53 (2.78)           | 5.07 (2.38)            | 5.84 (2.23)            | p=0.04* <sup>a</sup> ; ES=0.602   | p=0.08; ES=0.414    |
|                            | <b>CG</b> | 5.92 (1.77)           | 6.92 (1.38)            | 6.35 (1.69)            |                                   |                     |
| <b>Sensory Orientation</b> | <b>EG</b> | 4.03 (1.10)           | 5.00 (0.91)            | 4.76 (0.83)            | p=0.53; ES=0.119                  | p=0.001*; ES=0.986  |
|                            | <b>CG</b> | 5.78 (0.42)           | 5.50 (0.75)            | 5.57 (0.51)            |                                   |                     |
| <b>Stability of Gait</b>   | <b>EG</b> | 6.69 (1.88)           | 7.46 (1.39)            | 7.38 (1.50)            | p=0.05* <sup>b,c</sup> ; ES=0.857 | p=0.00*; ES=1.00    |
|                            | <b>CG</b> | 9.00 (0.78)           | 9.78 (0.42)            | 9.35 (0.74)            |                                   |                     |
| <b>Total</b>               | <b>EG</b> | 20.84 (6.80)          | 22.92 (5.18)           | 23.46 (5.65)           | p=0.00* <sup>b</sup> ; ES=0.802   | p=0.00*; ES=0.954   |
|                            | <b>CG</b> | 27.35 (2.67)          | 29.42 (2.06)           | 26.57 (3.47)           |                                   |                     |

APAs: anticipatory postural adjustments; sd: standard deviation; EG: experimental group, CG: control group. \*p≤0.05; <sup>a</sup>: statistically significant difference between pre-test and post-test in both groups; <sup>b</sup>: statistically significant difference between pre-test and post-test in CG; <sup>c</sup> statistically significant difference between post-test and follow-up in CG.

For cognition, there was no significant difference between groups (p = 0.143; ES = 0.307), and no interaction between time and group factors (p = 0.724; ES = 0.075). Between the initial evaluation and the long-term retention test, both groups showed improvements in their cognitive function (p = 0.006; ES= 0.823) (Figure 4). The groups had significant differences in the visuospatial, abstraction, and orientation domains. Regarding intragroup analysis, only the Memory domain presented a significant difference between the pre-test and the follow-up for both groups (p=0.04; ES=0.213).

**Table 3.** Cognition domains measured by the MoCA (Control Group - n=14; Experimental Group - n=13).

|                     |           | Pre-test<br>mean (sd) | Post-test<br>mean (sd) | Follow-up<br>mean (sd) | Intragroup analyses             | Intergroup analyses |
|---------------------|-----------|-----------------------|------------------------|------------------------|---------------------------------|---------------------|
| <b>Visuospatial</b> | <b>EG</b> | 3.30 (1.25)           | 3.38 (1.44)            | 3.23 (1.30)            | p=0.82; ES=0.078                | p=0.03*; ES=0.567   |
|                     | <b>CG</b> | 4.00 (0.87)           | 4.07 (0.73)            | 4.28 (1.20)            |                                 |                     |
| <b>Naming</b>       | <b>EG</b> | 2.84 (0.55)           | 2.92 (0.27)            | 2.69 (0.85)            | p=0.44; ES=0.182                | p=0.88; ES=0.052    |
|                     | <b>CG</b> | 2.71 (0.82)           | 2.92 (0.26)            | 2.92 (0.26)            |                                 |                     |
| <b>Attention</b>    | <b>EG</b> | 4.69 (1.37)           | 4.30 (1.54)            | 4.53 (1.50)            | p=0.32; ES=0.241                | p=0.36; ES=0.143    |
|                     | <b>CG</b> | 5.00 (1.03)           | 4.71 (1.43)            | 5.07 (0.99)            |                                 |                     |
| <b>Language</b>     | <b>EG</b> | 1.61 (1.04)           | 1.84 (0.68)            | 1.92 (0.64)            | p=0.37; ES=0.213                | p=0.58; ES=0.083    |
|                     | <b>CG</b> | 1.78 (1.05)           | 2.14 (1.23)            | 1.92 (0.91)            |                                 |                     |
| <b>Abstraction</b>  | <b>EG</b> | 1.00 (0.57)           | 1.07 (0.64)            | 1.23 (0.59)            | p=0.38; ES=0.209                | p=0.00*; ES=0.913   |
|                     | <b>CG</b> | 1.64 (0.49)           | 1.71 (0.46)            | 1.78 (0.57)            |                                 |                     |
| <b>Memory</b>       | <b>EG</b> | 2.61 (1.32)           | 3.23 (1.36)            | 3.53 (1.05)            | p=0.04* <sup>a</sup> ; ES=0.213 | p=0.54; ES=0.090    |
|                     | <b>CG</b> | 2.64 (1.27)           | 2.85 (1.23)            | 3.50 (1.65)            |                                 |                     |
| <b>Orientation</b>  | <b>EG</b> | 5.69 (0.63)           | 5.78 (0.42)            | 5.71 (0.46)            | p=0.89; ES=0.067                | p=0.01*; ES=0.768   |
|                     | <b>CG</b> | 6.00 (0.0)            | 6.00 (0.0)             | 6.00 (0.0)             |                                 |                     |
| <b>Total</b>        | <b>EG</b> | 22.30 (3.52)          | 23.23 (3.94)           | 23.61 (3.86)           | p=0.00* <sup>a</sup> ; ES=0.823 | p=0.14; ES=0.307    |
|                     | <b>CG</b> | 23.64 (3.17)          | 25.00 (3.41)           | 25.78 (2.88)           |                                 |                     |

sd: standard deviation; EG: experimental group, CG: control group. \*p≤0.05; <sup>a</sup>: statistically significant difference between pre-test and follow-up in both groups.

## DISCUSSION

The main findings showed that individuals with PD were able to learn the four selected games and maintained their performance after one week and one-month after the acquisition period.

Previous studies demonstrated that individuals with PD can learn different motor skills<sup>12,20</sup> and, more specifically, are able to learn postural control tasks<sup>12,26</sup> in a short interval (24 hours) between the acquisition and the retention test. Since the interval between acquisition and retention is critical for motor learning<sup>19</sup> our results showed that a different retention interval (one week and one month) in a task with high postural control demand did not impact negatively the motor learning of individuals with PD. Mendes<sup>34</sup>, conducted a study carrying out two retention tests, one in the short term, after one week without practice and another one in the long term (60 days after the end of the acquisition phase). As a result, the participants learned seven of the ten games played in the acquisition phase in the short-term retention, which remained during the long-term retention. The unlearned games involved stationary gait in dual-task condition, timing and object selection.

Based on Kantak and Winstein<sup>19</sup>, the motor learning process can be divided into three phases: encoding, consolidation and retrieval. Encoding is a process associated with practice that results in the formation of motor memory and is primarily thought to occur during the acquisition phase; consolidation is defined as a set of post-acquisition and becomes more stable with the passage of time; and retrieval is a fundamental process of learning<sup>19</sup>. By increasing the retention interval, long-term retention curves were seen, since individuals with PD retained the tasks in the long term. This is relevant, since in PD, there is the degeneration of the basal ganglia, responsible for the consolidation of the learned motor act<sup>14</sup>.

In our study, the proposed tasks have high demands on postural control. Peterson, Dijkstra, and Horak<sup>26</sup> investigated the learning of a task with demand for postural control only. The authors found that individuals with PD were able to learn anteroposterior postural protection responses to external disturbances, but they were not able to transfer it to mediolateral protection responses.

Regarding postural control, our results showed only the neurologically healthy elderly individuals were able to improve postural control evaluation performed through the MiniBESTest after practice the tasks<sup>35</sup>. We observed baseline differences between groups on postural control, which was expected, since PD often leads to postural instability, which is greater in individuals with PD<sup>36,37</sup>. It is known that scores below 20 points on the MiniBESTest are predictors of falls<sup>38</sup>. Our sample included some participants with PD at risk of falls. On the other hand, the domain analysis demonstrated individuals with PD were able to present improvements in the postural response's domain between pre and post-tests Mendes also evidenced that learning task with high postural control demand impact on postural control in PD individuals.

Both groups presented significant changes in cognition from the initial evaluation to the long-term retention test. Subsequent analyses confirmed that the changes in overall MoCA score were attributed to changes in the memory domain. Although the literature shows individuals with PD present cognitive deficits that worsen with disease progression<sup>2</sup>, our participants with PD had similar baseline MoCA scores than the neurologically healthy elderly<sup>28</sup>. However, participants in the EG had lower scores on the visuospatial, abstraction, and spatial and temporal orientation domains, as expected in PD<sup>2,39-41</sup>. Using the established cut-off score of 26/30 on the MoCA to indicate normal cognition, both groups had mild cognitive deficits at baseline<sup>28</sup>. Both groups showed statistically significant changes on the MoCA, but the group means remained under the cut-off of 26 points. It is not possible to conclude on the clinical impact of the changes, as the MoCA does not have established psychometric values for minimally detectable or clinically important for individuals with PD.

One limitation was the different number of individuals on each stage of the disease. Recruitment of participants at each stage of the disease, would allow a more in-depth analysis of motor learning during PD evolution. Additionally, it was not included other retention test. We are aware that repetition of the retention test after some time could give us the information of the critical interval for the learning of these motor skills.

This study brings new and promising directions for the future. The first one includes the retention interval. Future studies should include different intervals, e.g., after each month for a given period, to determine the critical interval of maintenance of motor learning in people with PD. Another question arising is whether the disease progression can impact motor learning process. Future studies should include individuals in all PD stages. Additionally, future studies should need to consider task adjustments to the task accomplishment in relation to various levels.

## CONCLUSION

Individuals with PD can learn tasks with a demand for postural control and retain in the short and long-term, despite inferior performance when compared to neurologically healthy elderly.

The learning of four tasks in a virtual environment led to an improvement in the cognition of the elderly and in individuals with PD, specifically in terms of memory, and in reactive aspects of the postural control for the elderly and for individuals with PD and gait stability only for the elderly.

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