Motor learning, retention and transfer after virtual-reality-based training in Parkinson’s disease – effect of motor and cognitive demands of games: a longitudinal, controlled clinical study

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Abstract

Objectives To evaluate the learning, retention and transfer of performance improvements after Nintendo Wii Fit™ training in patients with Parkinson’s disease and healthy elderly people.

Design Longitudinal, controlled clinical study.

Participants Sixteen patients with early-stage Parkinson’s disease and 11 healthy elderly people.

Interventions Warm-up exercises and Wii Fit training that involved training motor (shifts centre of gravity and step alternation) and cognitive skills.

A follow-up evaluative Wii Fit session was held 60 days after the end of training. Participants performed a functional reach test before and after training as a measure of learning transfer.

Main outcome measures Learning and retention were determined based on the scores of 10 Wii Fit games over eight sessions. Transfer of learning was assessed after training using the functional reach test.

Results Patients with Parkinson’s disease showed no deficit in learning or retention on seven of the 10 games, despite showing poorer performance on five games compared with the healthy elderly group. Patients with Parkinson’s disease showed marked learning deficits on three other games, independent of poorer initial performance. This deficit appears to be associated with cognitive demands of the games which require decision-making, response inhibition, divided attention and working memory. Finally, patients with Parkinson’s disease were able to transfer motor ability trained on the games to a similar untrained task.

Conclusions The ability of patients with Parkinson’s disease to learn, retain and transfer performance improvements after training on the Nintendo Wii Fit depends largely on the demands, particularly cognitive demands, of the games involved, reiterating the importance of game selection for rehabilitation purposes.

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Keywords: Parkinson’s disease; Motor learning; Virtual reality; Executive function; Rehabilitation; Transfer

Introduction

Motor rehabilitation can be characterised as a process of ‘relearning’ how to move to respond satisfactorily to the demands of daily living [1], and is based on the premise that training leads to improved performance both in terms of acquiring new skills and adapting or refining previously acquired skills [2]. Thus, knowledge on the effectiveness of the motor learning process in patients with Parkinson’s disease is pivotal for planning more effective rehabilitation strategies [3].

Evidence shows that the basal ganglia, particularly the striatum, play a role in the learning process [4]. However,
the extent to which dopamine depletion secondary to nigral degeneration seen in Parkinson’s disease impacts this process remains unclear. Therefore, although numerous studies have investigated motor learning in Parkinson’s disease, the results vary considerably [5–15].

In the absence of a clear picture of the changes during the learning process in Parkinson’s disease, and consequent lack of definitive guidelines for devising more effective rehabilitation strategies, it is important to investigate the learning potential of patients with Parkinson’s disease by applying new therapeutic strategies and validating their utility.

Virtual reality, defined as computer-based technology providing a multisensory environment with which the user can interact [16], has been proposed as a novel therapeutic tool for motor rehabilitation. Studies have identified a number of benefits derived from the use of virtual reality: (i) the performance of tasks that cannot feasibly be performed safely in a real-world environment; (ii) intensive repetition of complex tasks directed by visual and auditory stimuli which create dynamic patient–task interaction [17]; (iii) immediate feedback on performance and results; and (iv) a more motivating training environment [18].

Combined, these advantages can serve to facilitate the learning process in patients with Parkinson’s disease. To date, two previous studies have investigated the effects of training in a virtual environment in patients with Parkinson’s disease, both of which showed performance improvements in virtual reality and positive transfer [19,20].

Among the virtual reality devices with potential for use in rehabilitation, the Nintendo WiiTM stands out as a portable, easy-to-use, low-cost alternative that offers good reliability [21–23]. Some studies in elderly and brain-damaged patients have reported improvement in balance after training on Nintendo Wii FitTM games, whose interface incorporates a force platform, the Wii Balance BoardTM, that provides information on force distribution, enabling the player to control the displacement of their body’s centre of gravity in real time [23–26].

Despite the positive results reported by these preliminary studies, the criteria for game selection have yet to be addressed. Previous studies have employed several criteria, including: (i) predicted viability/benefit of games based on the movements performed during play [21,25], and (ii) choice/acceptance of the games by participants [27]. Thus, in spite of growing use of Wii Fit games in rehabilitation, there is a lack of criteria to help guide the use of Wii Fit as a therapeutic tool.

Given that motor and cognitive impairments in Parkinson’s disease can have a negative effect on the learning process, depending on the demands placed by the tasks trained, the authors hold that investigation into learning and retention in Wii Fit games with different characteristics, and into the transfer of their effects to real-life tasks, are of prime importance for defining criteria for the selection of games with greater therapeutic potential for this patient group. Therefore, the aim of this study was to investigate learning, retention and transfer of learning in patients with Parkinson’s disease for 10 Wii Fit games that place different motor and cognitive demands on players.

The authors hypothesised that, depending on the motor and cognitive requirements of the games, patients with Parkinson’s disease, after extensive training, will be able to learn, retain and transfer learning to a similar motor task, with or without deficits compared with healthy elderly people. The results of this study will demonstrate the limitations and therapeutic potential of Wii Fit games for rehabilitation of patients with Parkinson’s disease.

Methods

Subjects

Sampling size was calculated using the mean score on the Torso Twists (TTW) Wii Fit game, based on a pilot study which showed that patients with early-stage Parkinson’s disease and healthy elderly people had the same baseline performance on this game. Thus, a mean initial value was set at 70, with a standard deviation of 12, taking 20 points as the difference between pre- and post-training scores. The result indicated that 18 participants (nine per group) would be required to attain 90% power. Therefore, 16 patients with Parkinson’s disease and 11 healthy elderly people were recruited, allowing for potential losses during the study period. All participants completed the study and were included in the analysis.

The patients with Parkinson’s disease (two at Stage 1 and 14 at Stage 2 on the Hoehn and Yahr staging scale), undergoing treatment with levodopa, were recruited from Parkinson’s associations and assigned to the experimental group. The healthy elderly people, matched for age and gender, were recruited from third age associations and assigned to the control group. Inclusion criteria for the study were absence of neurological disease (excluding Parkinson’s disease for the experimental group) or detectable orthopaedic problems, a minimum score of 24 on the Mini-Mental State Examination [28], a maximum score of 5 on the Geriatric Depression Scale-15 items [29], normal or corrected visual acuity, and good auditory acuity. Participants had no prior experience with the Wii Fit games and were not participating in any other rehabilitation programmes. All participants signed an informed consent form prior to study commencement. The study was approved by the Research Ethics Committee of São Camilo University.

Procedures

Prior to commencing training, the participants performed a right-side functional reach test [30]. This test enables assessment of the limits of stability in the standing position by measuring the maximum distance that a participant can reach laterally with their right arm, without moving or lifting their feet from the floor.
The functional reach test was repeated 1 week and 60 days after the end of training (Fig. A, see online supplementary material).

Training

Both groups underwent 14 twice-weekly individual training sessions, overseen by a physiotherapist. Sessions were run on the same days each week and at the same time. Prior to embarking on the first training session, the games were demonstrated by the physiotherapist, who explained the objectives of each game. Subsequently, in order to familiarise patients with the task and device, participants were allowed two practice trials per game.

Sessions began with a 30-minute warm-up consisting of global mobility exercises. This was followed by training on Wii Fit games as shown in Table 1.

Table 1
Games training schedule, and their main motor and cognitive demands.

<table>
<thead>
<tr>
<th>Sessions 1, 3, 5, 7, 9, 11 and 13</th>
<th>Main motor demands</th>
<th>Main cognitive demands</th>
<th>Sessions 2, 4, 6, 8, 10, 12 and 14</th>
<th>Main motor demands</th>
<th>Main cognitive demands</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table Tilt</td>
<td>Shift centre of gravity slowly in all directions with feet in a fixed position</td>
<td>Plan movements in order to hit targets</td>
<td>Basic Run Plus*</td>
<td>Perform stationary walk as fast as possible on soles</td>
<td>Divide attention between gait and task to memorise greatest number of items of information about course to answer questions posed at end of each trial</td>
</tr>
<tr>
<td>Obstacle Course</td>
<td>Perform stationary walk as fast as possible, halt and resume walking</td>
<td>Decide on best walking speed, when to halt and resume, response inhibition</td>
<td>Basic Step</td>
<td>Alternate steps mounting and dismounting Wii Balance Board, according to rhythm determined by game</td>
<td>Sustain attention to follow visual and auditory cues which direct foot movements</td>
</tr>
<tr>
<td>Rhythm Parade</td>
<td>Perform stationary walk to auditory and visual rhythm provided by game, while performing flexo-extension of elbows in different rhythm to walk</td>
<td>Divide attention between gait and task of hitting random targets with one or both arms</td>
<td>Torso Twists</td>
<td>Perform torso twists, moving arms and keeping feet still while remaining stable</td>
<td>Sustain attention to mimic movements shown by avatar, self-awareness</td>
</tr>
<tr>
<td>Tilt City</td>
<td>Shift centre of gravity sideways keeping feet still while moving arms</td>
<td>Identify colour of stimulus and plan arm and hip movements to direct targets to point with corresponding colour</td>
<td>Soccer Heading</td>
<td>Shift centre of gravity latero-laterally while keeping feet still</td>
<td>Identify stimulus and decide quickly on direction of movements to hit or dodge target, response inhibition</td>
</tr>
<tr>
<td>Single Leg Extension</td>
<td>Balance on one leg while moving arms and leg contralaterally while remaining stable</td>
<td>Sustain attention to mimic movements shown by avatar, self-awareness</td>
<td>Penguin Slide</td>
<td>Shift centre of gravity latero-laterally while keeping feet still</td>
<td>Plan movements of avatar towards targets</td>
</tr>
</tbody>
</table>

* Not played on Wii Balance Board.

except for constant verbal encouragement; the final score from the second attempt was recorded for later analysis of the intersession learning curve. Participants were allowed to rest between each exercise and/or game according to individual needs. Sixty days after the last training session, an additional session was conducted in which participants had two attempts at each of the 10 games in order to determine learning retention.

The 10 Wii Fit games were selected based on their motor and cognitive requirements. After analysis of the whole repertoire of games available by three physiotherapists, 10 games were selected. Table 1 shows the training schedule for the games, together with their motor and cognitive demands. In terms of motor demands, four games required multidirectional shifts in the player’s centre of gravity [Table Tilt (TT), Tilt City (TC), Penguin Slide (PS), Soccer Heading (SH)], four games involved alternating steps [Obstacle Course (OC), Rhythm Parade (RP), Basic Run Plus (BRP), Basic Step (BS)], and two games required stationary control of the player’s centre of gravity [Single Leg Extension (SLE), TTW]. For cognitive demands, all 10 games involved attention, rapid responses to visual stimuli and performance assessment by visual and auditory feedback between trials.
Table 2: Participants’ characteristics at baseline.

<table>
<thead>
<tr>
<th></th>
<th>Experimental group (n = 16)</th>
<th>Control group (n = 11)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>68.6 (8.0)</td>
<td>68.7 (4.1)</td>
<td>0.98⁴</td>
</tr>
<tr>
<td>Disease duration (years)</td>
<td>4.7 (5.4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mini-Mental State</td>
<td>27.2 (1.9)</td>
<td>28.3 (1.1)</td>
<td>0.18⁴</td>
</tr>
<tr>
<td>Examination (score)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geriatric Depression</td>
<td>3.6 (1.8)</td>
<td>2.4 (1.6)</td>
<td>0.12 ⁸</td>
</tr>
<tr>
<td>Scale (score)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Data shown as mean (standard deviation).
⁴ t-test.

Three of the games required planning (TT, PS and TC), two games involved a dual motor task (RP and TC), one game required a dual motor and cognitive task (BRP), and two games entailed decision-making and response inhibition (OC and SH).

Data analysis

Differences in demographic and clinical characteristics between the subjects in the two groups at baseline were tested using Student’s t-test.

Learning curve and retention were rated based on the scores for the second attempt at each game in the first seven sessions and the eighth session, respectively, for each of the 10 games. After normality and homogeneity testing, repeated measurements analysis (2 × 8) was applied to compare each independent variable (score on each of the 10 games), using group as the factor (control group and experimental group) and the sessions (Session 1, Session 2, …, Session 7 and retention) as the repeated measure. Tukey–Kramer’s post hoc test was applied for effects that reached a 5% level of significance in order to carry out pair-wise, inter- and intragroup comparisons.

In order to determine the transfer of learning, the effect of training on the games was tested based on the functional reach test. Values (in cm) attained by patients with Parkinson’s disease before training, 1 week after training and 60 days after training were compared using one-way repeated-measures analysis of variance. All analyses were performed using Statistica Version10 (StatSoft, Tulsa, OK, USA).

Results

Demographic and clinical characteristics

Table 2 shows the characteristics of subjects in the experimental and control groups at baseline. No significant differences were observed between the two groups.

Learning and retention

The scores attained on the games in the training and retention sessions (Table A, see online supplementary material) were classified according to the effects on analysis of variance.

Games in which the experimental and control groups had the same performance and same learning and retention capacity

For TT and SLE, repeated-measures analysis of variance only revealed a session effect, with no group effect or interaction between factors. The post hoc test showed a significant improvement between Session 1 and Session 7, and between Session 1 and retention for TTW and SLE, respectively (Table A, see online supplementary material).

Therefore, the patients with Parkinson’s disease showed no performance, learning or retention deficits on these games compared with healthy elderly people.

Games in which the experimental group had impaired performance, but the same learning and retention capacity compared with the control group

For RP, TT, TC, BS and PS, the repeated-measures analysis of variance revealed a group effect and session effect, with no interaction between factors. The post hoc test showed significant improvements from Session 1 to Session 2 for BS, from Session 1 to Session 3 for RP and PS, and from Session 1 to Session 6 for TC, and confirmed differences between the groups for RP, TT, TC, BS and PS (Table A, see online supplementary material).

In summary, the patients with Parkinson’s disease had the same learning and retention capacity following training as healthy elderly people, despite having a poorer performance on these games.

Games in which the experimental group exhibited deficits in learning and retention capacity

For OC, SH and BRP, repeated-measures analysis of variance revealed interaction between session and group. For OC (Table A, see online supplementary material), on intragroup analysis, post hoc test only showed a significant improvement between Session 1 and Session 7, and Session 1 and retention for the participants in the control group. Intergroup analysis showed a significant difference in performance between the groups at Session 7 which persisted to retention (Fig. 1).

This difference was also observed for SH (Table A, see online supplementary material). On intragroup analysis, the post hoc test showed a significant improvement between Session 1 and Session 7, and Session 1 and retention for the participants in the control group. Intergroup analysis showed a significant difference in performance between the groups at Session 7 which persisted to retention (Fig. 2). For BRP, intragroup analysis showed a significant improvement between Session 1 and Session 7, and Session 1 and retention for the participants in the control group (Table A, see online supplementary material), while intergroup analysis showed a significant difference in performance at Session 1 which persisted to retention (Fig. 3).
In summary, the patients with Parkinson’s disease exhibited deficits in learning and retention on these games compared with healthy elderly people; for OC and SH, this deficit led to impaired performance during later sessions. However, for BRP, the impaired performance seen in the first session worsened after training.

**Transfer of learning – effect on functional reach test**

One-way repeated-measures analysis of variance revealed an assessment effect ($F = 7.19$, $P = 0.003$, power = 0.90) for the test of left functional reach, performed before training, 1 week after training and 60 days after training for patients with Parkinson’s disease. This was confirmed by the post hoc test which showed a significant improvement between before training and 1 week after training ($P = 0.003$), and before training and 60 days after training ($P = 0.02$). Therefore, the patients with Parkinson’s disease were able to transfer a motor ability trained on the games to a similar untrained task.

**Discussion and conclusions**

This study investigated the ability of patients with Parkinson’s disease to learn, retain and transfer learning on 10 Wii Fit games requiring different motor and cognitive skills in comparison with healthy elderly people. The authors’ hypothesis was that, depending on the motor and cognitive requirements of the games, the patients with Parkinson’s disease would exhibit deficits in learning and retention compared with healthy elderly people.

The results confirmed this initial hypothesis, showing that patients with Parkinson’s disease had normal learning and retention on seven games (TTW, SLE, RP, TT, TC, BS and PS) compared with healthy elderly people, but had worse performance on five games (RP, TT, TC, BS and PS). The patients with Parkinson’s disease were unable to improve their performance on three games following training (OC, SH and BRP), whereas the healthy elderly people demonstrated good learning and retention.

Given that the training conditions and number of trials were the same for all games, the difference in the ability of patients with Parkinson’s disease to improve performance may be attributed solely to the different demands of the games.

Concerning motor requirements, two of the three games for which patients with Parkinson’s disease displayed no learning involved stationary gait (OC and BRP), whereas the third game involved rapid multidirectional shifts in the player’s centre of gravity (SH), placing similar demands as five other games (RP, BS, TT, TC and PS) for which the patients with Parkinson’s disease showed normal learning compared with healthy elderly people.

For cognitive demands, two of the games for which the patients with Parkinson’s disease failed to improve required fast decision-making in hitting or avoiding stimuli displayed on screen (SH), and in speeding up or halting gait to avoid visual obstacles presented during a virtual journey (OC). Although all of the games require several cognitive functions, such as attention, memory and planning, only these
two games required decision-making upon encountering new stimuli. In the third game for which the patients with Parkinson’s disease showed learning deficits, players had to answer three varied questions at the end of a virtual walk about the visual stimuli displayed along the way. The stimuli and the questions varied, in order to preclude memorising the answers between trials. Thus, the game simulated dual-tasking conditions where attention is divided between motor tasks (alternating steps) and cognition, registering several stimuli presented for later recall – a task which also relies on working memory. It is noteworthy that, for two other games requiring divided attention between upper and lower limb movements (RP and TC), the patients with Parkinson’s disease had no deficits in learning and retention despite having a poorer performance than healthy elderly people.

Taken together, these results suggest that motor difficulties can impair the performance of patients with Parkinson’s disease on the majority of games, but they do not affect the ability to improve performance with practice or to retain these benefits after training. However, impairment in some cognitive functions, particularly quick decision-making and management of attention and/or working memory, may have hampered learning on some games.

Several studies have reported preserved motor learning ability in patients with Parkinson’s disease [5,6], especially under training conditions which present visual, auditory and/or proprioceptive stimuli that serve to direct performance [31,32] and/or provide feedback on performance [31,33]. To the authors’ knowledge, this is the first study reporting this phenomenon on different and complex tasks in the same group of patients.

However, among those studies that have identified learning deficits in patients with Parkinson’s disease, some have discussed the mechanisms by which cognitive aspects can affect results [34]. Several studies have shown that dopamine depletion in internal circuits of the basal ganglia, and consequent compromise of the efficacy of communication pathways connecting pre-frontal and cortical pre-motor areas, can cause the cognitive deficits associated with Parkinson’s disease. Executive functions are particularly affected, including attention, planning, decision-making, response inhibition and working memory, and there is a negative effect on the motor performance of patients [35,36], compromising their functionality [37]. Some studies have shown that patients with Parkinson’s disease are particularly affected on tasks requiring decision-making and divided attention [38], response inhibition [35] and working memory [39].

Moreover, patients with Parkinson’s disease were able to transfer a motor ability trained on the games to a similar untrained task. Although some studies have shown deficits in the ability of patients with Parkinson’s disease to transfer or generalise performance improvement to similar tasks [40], the present study indicated that patients improved their ability to shift their centre of gravity, trained on some of the Wii Fit games. These findings confirmed those of earlier reports showing that the effects of training with virtual reality are transferable in patients with Parkinson’s disease [19,20].

This is an important finding which points to the therapeutic potential of this type of training. Additional studies are needed to further investigate the transfer of learning between this type of game and other functional activities.

Based on these results, it can be concluded that the ability of patients with Parkinson’s disease to learn, retain and transfer performance improvements after extensive training on Wii Fit games depends largely on the demands, particularly cognitive, of the specific games involved.

Thus, among the games tested, those in which patients exhibited no learning deficit (SLE, TTW, RP, TT, TC, BS and OS) have the greatest indication for therapeutic use, whereas games for which patients showed no improvement during training (OC, SH and BR) have low therapeutic potential.

This finding reiterates the importance of game selection for rehabilitation purposes, and represents the main clinical outcome of this study. Further studies are warranted to confirm the transfer of learning to activities of daily living, thereby enabling training in virtual environments to be validated for patients with Parkinson’s disease.

Ethical approval: Research Ethics Committee of the São Camilo University (Ref. No.: CAAE – 0166.0.166.000-8).

Conflict of interest: None declared.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.physio.2012.06.001.

References


