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Effects of virtual rehabilitation on postural control of individuals with Parkinson disease

Efeitos da reabilitação virtual no controle postural de indivíduos com doença de Parkinson

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ABSTRACT

Parkinson's disease causes a progressive decline of motor and cognitive functions, often affecting postural control. Training through virtual reality has been shown to be effective in improving this condition. This study aims to analyse the effects of the Kinect Adventures! games in postural control of people with Parkinson's disease. Ten individuals diagnosed with idiopathic Parkinson's disease, in stages I to III of the Hoehn & Yahr scale, aged between 48 and 73 years, were selected. Fourteen training sessions of one hour each, twice a week, were performed. Individuals were evaluated pre, post-intervention and 30 days after the last session of intervention by a force platform that measured the oscillation area and velocity of the centre of pressure in ten different sensory conditions and the Limits of Stability. Limits of Stability showed a statistically significant increase immediately after the training the 14 sessions, as were observed and there were no significant changes in oscillation area and velocity immediately after the intervention or 30 days after the end of training. The results of this study indicate that the training with Kinect Adventures! Games improve the postural control of people with Parkinson's disease, by increasing the Limits of Stability.

KEYWORDS: Parkinson disease; postural balance; virtual reality exposure therapy; video game.

INTRODUCTION

Parkinson's disease (PD) affects the central nervous system, being degenerative, chronic, and progressive (Benjamin & Joseph, 2001).

PD is the second most common senile disease (De Rijk et al., 1997), while the first is Alzheimer's disease. In Brazil, 3.4% of the population over age 64 is affected by the disease (Barbosa et al., 2006). PD incidence increases significantly with age, ranging from 17.4 to 93.1 out of 100.000 in people aged between 50 to 59 and 70 to 79, respectively.

The cardinal signs of PD are rigidity, bradykinesia, tremor, and poor posture (Souza et al., 2001), and it also compromises the cognitive and perceptual functions (Hamani & Lozano, 2003). The posture instability is one of the most limiting symptoms of the disease (Waterston, Hawken, Tanyeri, Jantti, & Kennard, 1993; Pompeu et al., 2012; Doná et al., 2015). In the light and moderate stages of the disease, it is noted a decrease in the area of the stability limit (Doná et al., 2015), even on the period *on* of dopaminergic replacement (Mancini, Rocchi, Horak, & Chari, 2008; Menant, Latt, Menz, Fung, & Lord, 2011). Fukunaga et al. (2014) showed that individuals with PD have more posture instability than healthy individuals considering changes in the distribution of weight, in the synchronization of postural oscillation right/left and toes/heel, in the frequency bands of postural oscillation and in the risk of tumbling.

Individuals with PD fall twice as much as elderly people without the disease (Dibble, Christensen, Ballard, &

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Foreman, 2008). Besides, the incidence of people with PD falling increases as time passes, suggesting that individuals with the disease are falling earlier over the years (Wood, Bilclough, Bowron, & Walker, 2002). Approximately 75% of people with PD have their balance harmed (Nilsson, Hariz, Iwarsson, & Hagell, 2012). The fear of falling is the biggest reason they do not practice any kind of physical exercise (Ellis et al., 2013). Because of that, new interventions are being proposed to improve the posture control of people with PD, being interactive video games among the suggestions (Pompeu et al., 2012; Pompeu et al., 2014).

The Kinect® from X-Box 360® is an updated system of the video game, developed from the movement reception by infrared, in a way that the player does not need platforms or controls to play, having more freedom in the movements to interact with the games. It is also a commercial videogame, easy to be accessed and portable.

Individuals with PD need higher cognitive engagement to perform motor tasks related to daily living activities. Also, more cognitive demand is involved in the motor learning process. Besides, motivation and feedback can reduce the motor learning deficit in PD. Visual and auditory external cues can help PD patients to maintain motivation and attention to perform the previously automatic movements (Mazzoni & Wexler, 2009; Redgrave et al., 2010; Wu & Hallett, 2007; Petzinger et al., 2013). The X-Box Kinect® promotes visual, auditory, motor, and cognitive stimuli, which can help the motor sensorial integration reflecting positively in postural control training (Pedalini & Bittar, 1999; Galna et al., 2014; Pompeu et al., 2014).

The Kinect games integrate three elements that are essential to motor learning: repetition, motivation, and feedback (Holden, 2005), being able to facilitate the learning and transference of abilities to daily life (Conradsson et al., 2015; Mendes et al., 2015). Once motor, cognitive and sensorial stimulus can help to modify, repair, and develop new neural networks, virtual reality could promote an improvement in motor behaviour, more specifically in postural control of this population (Sudhof & Malenka, 2008)."

The use of virtual reality games with patients with PD is recent, and there are still few studies that verified the aspects related to the games in the symptoms of the disease (Barry, Galna, & Rochester, 2014). Considering that postural instability is the most refractory cardinal sign of PD to the dopaminergic replacing treatment (Latt, Lord, Morris, & Fung, 2009), and that tumbles, walking conditions, and postural instability might lead to higher mortality and morbidity of people with PD (Ebmeier et al., 1990; Bennett et al., 1996), studies that evaluate, through quantitative methods, the effects of new interventions with chances to improve the postural control, such as the case with virtual reality games, are necessary.

Finally, this study aims to analyze the effects of training through Kinect Adventures! Games on the area of the stability limits and postural oscillation in conditions of static and non-static visual environment in people with PD.

METHODS

The study refers to a range of cases analyzed in the Center of Teaching and Research of the Physical Therapy, Speech and Occupational Therapy, Faculty of Medicine at the University of Sao Paulo, Sao Paulo, Brazil.

The present research was approved by the Ethical Committee of the *Universidade Federal de Sao Paulo*, with the number 226.672.

Participants

Ten subjects were selected, aged between 48 and 73, with the PD idiopathic, diagnosed by neurologists specialized in extrapyramidal diseases, according to the Brain Bank of the Parkinson Society criteria from the United Kingdom (Hughes, Daniel, Kilford, & Lees, 1992).

All selected subjects were between stage I and III in the Hoehn and Yahr scale; they were under drug-based treatment with Levodopa and/or their synergistic; they did not present any other detectable neurologic or orthopedic disease; they did not present any clinical sign of dyskinesias; they all had a Mini-Mental State Examination score higher than 22 (Folstein, Folstein, & Mchugh, 1975; Brucki, Nitrini, Caramelli, Bertolucci, & Okamoto, 2003; Holden, 2005; Mendes, 2015), with average grade adjusted by schooling (illiterate people: 17; 1 to 4 years old: 23; 5 to 8 years old: 25; 9 years old or older: 22); all had regular or corrected visual and hearing acuity; subjects did not have previous experience with Kinect system, and could not start or stop a rehabilitation program throughout the study.

Subjects who presented any kind of clinical change, such as cardiorespiratory, orthopedic, or neurologic changes, inhibiting the achievement of physical exercises in two feet standing, or individuals who did not agree in signing Free and Clarified Consent term of the study were excluded.

Measures

It was collected the oscillation area of the center of pressure (COP) and oscillation velocity of the center of pressure (VOS), besides the Limits of Stability (LOS), using a force plate the *Balance Rehabilitation Uniti* (BRU). The equipment measures the elliptical area corresponding to 95% of the time gap of confidence in the excursions to the COP in the middle lateral to rearward directions and the VOS. The COP and VOS were quantified in static and non-static visual environments. The BRU software sends a stimulus to a head-mounted display (HMD; eMagin Z800 3D Vision, New York, NY, USA), eliciting oculomotor reflexes (saccades, optokinetic, and vestibulo-ocular).

The LOS test evaluates the ability to displace the COP in anteroposterior and lateral planes without risk of falling. An increase in LOS indicates good stability meaning that the individual has a higher area to sway with stability in daily activities. COP represents the vertical projection of the center of mass onto the ground (Tamburella, Scivoletto, Iosa, & Molinari, 2014), and its displacements were used to estimate the COP sway area used in this study. Anteroposterior (COPap) and mediolateral (COPml) displacement were recorded at a sampling frequency of 50 Hz (Suarez et al., 2011). The VOS means how fast the COP displacements occur. The lower the COP and VOS values, the greater the individual's static stability. This happens because it is expected that in a good static postural control, there will be a smaller area of oscillation of the COP and a smaller velocity of oscillation of the COP in this small existing area, corroborating with a more efficient strategy of maintaining posture.

To evaluate the LOS, the participants remained standing on the BRU in orthostatic posture and stretched arms through the body. After that, they were asked to move in rearward and middle lateral directions, through ankle movements, without having upper body movements. To evaluate the COP and the VOS, the participants were instructed to remain in a quiet position for 60 seconds in each of the 10 sensorial conditions tested. The conditions tested were:

1) orthostatic position on a hard floor, eyes open;
2) orthostatic position on a hard floor, eyes closed;
3) orthostatic position on the surface of foam pad, eyes closed;
4) orthostatic position on a hard floor, sacral stimulation;
5) orthostatic position on a hard floor, optokinetic stimulation with horizontal direction from the left to the right;
6) orthostatic position on a hard floor, optokinetic stimulation with horizontal direction from the right to the left;
7) orthostatic position on hard floor, optokinetic stimulation with vertical direction from the top to the bottom;
8) orthostatic position on a hard floor, optokinetic stimulation with vertical direction from the bottom to the top;
9) orthostatic position on a hard floor, optokinetic stimulation with horizontal direction associated to slow and uniform movements of rotation of the head;
10) orthostatic position on a hard floor, optokinetic stimulation with vertical direction associated to slow and uniform movements of flexo-extension of the head.

Virtual reality Glasses were used from the fourth to the tenth condition. In these conditions, the glasses promoted visual stimulus capable of giving postural reflex responses.

The sensory conditions tested aim to promote the assessment of static postural control of individuals in different environments, as in real life, since they encounter different surfaces and visual stimuli and need to react to some of them in daily life.

Procedures

The participants were evaluated by a blind evaluator in three moments: pre-intervention; immediately after the intervention; and after 30 days after the end of the intervention. The evaluation collected data of their LOS, COP and VOS under ten different sensorial conditions.

The intervention was composed of 14 individuals one-hour sessions, twice a week, during seven weeks, scheduled in a way that was combined with the period on dopaminergic replacement medication. In the sessions, the participants played 4 different games of the program Adventure! From the Kinect®, having 5 chances in each game. In the first session, each game was shown one time to the participant. Then, the participant had two chances of familiarity with each game, with a physiotherapist helping through verbal orders and manual guiding to correct their movements and posture and guide the participant concerning the objectives of the game. After it, the participant had 5 chances in each game without corrections from the physiotherapist, and the scores were registered.

The games selected for the interventions were:

(1) 20,000 Leaks;
(2) Space Pop;
(3) Reflex Ridge;
(4) River rush.

In the game "20,000 leaks", the player's avatar is in a glass cube underwater, and suddenly fish and sharks start to cause cracks and holes in the cube. The player's objective is to plug the cracks to avoid having water inside the glass cube, using their hands and feet, which require fast movements of these parts of the body. In the game "Space Pop", transparent balls (soap bubbles) shuttle between holes on the walls, floors and ceilings. The player attempts to pop the bubbles by touching them with their hands, moving their arms up and down just like a bird. In the game "Reflex Ridge", the player races on a platform, jump over hurdles, lean away from obstacles and limbo to avoid hitting their heads on low beams. In the game "River rush" the player's avatar stands in a raft and goes down the river. The raft is controlled by stepping left or right to steer and jumping to jump the raft.

In general, the games stimulated the individuals to move in different directions in a fast and controlled way, walk in different directions, move their centre of mass, sit down and jump, move their upper and lower body in a coordinated way and move their upper body in the three plans of movements. Besides, the games presented cognitive demands such as taking decisions quickly, monitoring the place, selecting visual stimuli, unwanted responses and divided attention (Pompeu et al., 2014; Mendes et al., 2015).

Statistics analysis

The patients' demographic and clinical data were collected, and normality and homogeneity tests were carried out through the Kolmogorov-Smirnov and Levene tests, respectively. For the parametric variables, that were the LOS and the COP in three out of the ten different sensorial conditions (stable ground with closed eyes, stable ground with optokinetic vertical stimulus from the top to the bottom, and stable ground with vertical optokinetic stimulus associated with the flexo extension of the head), the comparisons in the three conditions (before, after the intervention, and 30 days after the intervention) were made using the ANOVA. The non-parametric variables involved the other seven sensorial conditions of the COP and the ten sensorial conditions in which the VOS was also tested. Kruskal Wallis tests were carried out. The alpha was set at 0.05, and the Confidence interval was 95%.

RESULTS

Table 1 presents the clinical and demographic characteristics of the participants of this study. The majority of the participants were classified in stage 1.5 of Parkinson's Disease, according to the Hoehn and Yahr scale, presenting unilateral and axial involvement.

Table 2 presents the results for parametric data, which were the LOS and three out of ten sensorial conditions in which the COP was evaluated. There was a significant increase in the LOS immediately after the intervention with the Kinect and maintenance of results after 30 days following the intervention's end. Concerning COP's three conditions, no significant decrease was observed in the oscillation area after the intervention as well as 30 days after the end of the intervention. However, in the three conditions, COP's average decreased

Table 1. Clinical and demographic characteristics.

Characteristics	Average (CI) or n (%)
Age, years	63.4 (56.7–70.1)
Women, n (%)	4 (40)
HY, n (%)	1.85 (1.4–2.3)
Stage 1	2 (20)
Stage 1,5	3 (30)
Stage 2	2 (20)
Stage 2,5	2 (20)
Stage 3	1 (10)
MEEM, escore	27.4 (25.6–29.2)
Schooling, years	10.6 (7.1–14.1)

CI: confidence interval; HY: Hoehn and Yahr scale; MESE: Mini-Mental State Examination.

Table 2. Effects of Kinect in sway of the center of body-pressure area in individuals with Parkinson's disease (n= 10) pre-intervention, post-intervention and 30 days after intervention (parametric data).

	Pre-intervention average (CI)	Post-intervention average (CI)	30 days after intervention average (CI)	p*		MDC
				Pre x post	Post x 30 days after	
LOS (cm^2)	126.1 (88.5–163.7)	161.1 (122.7–199.5)	165.3 (127.8–202.8)	< 0.05	> 0.05	46.1
COP (cm^2) Stable ground, CE	3.5 (1.6–5.4)	3.0 (1.4–4.7)	2.3 (1.1–3.6)	> 0.05	> 0.05	2.3
COP (cm^2) Stable ground, VOS from the top to the bottom	4.5 (0.9–8.0)	3.0 (1.2–4.7)	3.5 (1.5–5.5)	> 0.05	> 0.05	2.2
COP (cm^2) Stable ground, VOS flexo-extension head	4.7 (2.9–6.6)	4.6 (3.2–6.1)	6.1 (3.8–8.4)	> 0.05	> 0.05	2.3

CI: confidence interval; LOS: limits of stability (cm^2); COP: sway of the center of body-pressure area (cm^2); CE: closed eyes; VOS: vertical optokinetic stimulus; MDC: minimmal detectable changes. *Analysis by ANOVA; Test after Hoc de Tukey.

immediately after the intervention. In one of them, this reduction remained with lower numbers than the ones obtained in the pre-intervention until 30 days after the intervention.

The non-parametric data referring to COP in the other 7 sensorial conditions evaluated are presented in Table 3. No significant decrease of COP was observed in any of the sensorial conditions, nor after the intervention, or 30 days after the end of the intervention. In most of the conditions presented, it is possible to observe a tendency to increase the medians of the COP in the two evaluations after the end of the intervention.

Table 4 shows the results of the non-parametric data of VOS in 10 sensorial conditions tested. No significant alteration was observed of the VOS in none of the sensorial conditions.

Table 3. Effects of Kinect in sway of the center of body-pressure area in individuals with Parkinson's disease (n= 10) pre-intervention, post-intervention and 30 days after intervention, medians (non parametric data).

	Pre-intervention median (interquartile range)	Post-intervention median (interquartile range)	30 days after intervention median (interquartile range)	p*		MDC
				Pre x post	Post x 30 days after	
Stable ground, EO	2.4 (3.2)	2.7 (4.8)	2.7 (3.1)	> 0.05	> 0.05	2.7
Unstable ground, CE	8.0 (4.5)	7.1 (10.6)	8.6 (6.5)	> 0.05	> 0.05	5.7
Stable ground, SS	1.6 (3.2)	2.6 (3.2)	2.2 (1.8)	> 0.05	> 0.05	3.3
Stable ground, OHS from L to R	2.4 (1.7)	2.4 (1.3)	2.8 (1.9)	> 0.05	> 0.05	6.4
Stable ground, OHS from R to L	1.9 (2.7)	2.7 (2.4)	2.8 (2.1)	> 0.05	> 0.05	3
Stable ground, VOS from bottom up	2.1 (3.2)	2.6 (2.5)	2.9 (2.6)	> 0.05	> 0.05	5
Table ground, OHS head rotation	3.9 (4.3)	2.9 (5.6)	4.7 (5.5)	> 0.05	> 0.05	3.4

COP: sway of the center of body-pressure area (cm^2); EO: eyes open; SS: saccadic stimulus; OHS: optokinetic horizontal stimulus; L: left; R: right; VOS: vertical optokinetic stimulus; MDC: minimmal detectable changes. * Analysis by Kruskal Wallis test.

Table 4. Effects of Kinect in the vertical optokinetic stimulus in individuals with Parkinson's disease (n= 10) pré-intervention, post-intervention and 30 days after intervention, median (non parametric data).

	Pre-intervention median (interquartile range)	Post-intervention median (interquartile range)	30 days after intervetion median (interquartile range)	p*		MDC
				Pre x post	Post x 30 days after	
Stable ground, EO	0.7 (0.6)	0.8 (0.3)	0.9 (0.3)	> 0.05	> 0.05	0.3
Stable ground, CE	1.0 (0.2)	1.0 (0.4)	1.0 (0.2)	> 0.05	> 0.05	0.2
Unstable ground, CE	2.0 (0.5)	2.0 (1.7)	2.1 (0.6)	> 0.05	> 0.05	0.7
Stable ground, SS	0.9 (0.4)	1.0 (1.7)	1.3 (0.5)	> 0.05	> 0.05	0.4
Stable ground, OHS from L to R	1.0 (0.8)	0.8 (0.5)	1.0 (0.3)	> 0.05	> 0.05	0.4
Stable ground, OHS from R to L	0.9 (0.7)	1.0 (0.3)	1.1 (0.4)	> 0.05	> 0.05	0.4
Stable ground, VOS from top to bottom	1.1 (0.6)	0.9 (0.2)	1.0 (0.3)	> 0.05	> 0.05	0.4
Stable ground, VOS, from bottom to top	1.0 (0.4)	1.0 (0.3)	1.0 (0.3)	> 0.05	> 0.05	0.4
Stable ground, OHS, head rotation	1.7 (0.7)	1.6 (0.6)	1.6 (0.6)	> 0.05	> 0.05	0.9
Stable ground, VOS, flexo- extension head	1.8 (0.6)	1.8 (0.3)	2.3 (0.8)	> 0.05	> 0.05	0.4

VOS: velocity of oscillation in the center of body pressure (cm/s); EO: eyes open; CE: closed eyes; SS: saccadic stimulus; OHS: optokinetic horizontal stimulus; L: left; R: right; VOS: vertical optokinetic stimulus; MDC: minimmal detectable changes. * Analysis by Kruskal Wallis test.

DISCUSSION

This study analyzed the postural control of people with PD before, after, and after 30 days of intervention using Kinect® X-Box 360®.

The results of this study indicate a significant increase in the LOS immediately after the intervention, which means that the participants had an increase in the stability area, in other words, an increase in the area of rearward and lateral mobility through ankle movements. These increases allowed a better displacement of weight during the performance of tasks, better stability guaranteed, reducing the chances for these people to fall (Shenkman, 2011). In this way, the increase of LOS indicates that the patient presents a bigger area to sway without the risk of falling.

Besides, the recovery of balance is done under three strategies: ankles, hips, and step. The adjustment of the ankles is the first balance strategy activated by a slight disruption that moves the center of mass of a person's body. Therefore, the increase of the LOS indicates a better efficacy in the balance recovery, once the disruption has to be bigger to avoid the balance recovery by the ankles strategy and activate the hips strategies (Folstein et al., 1975; Hughes et al., 1992; Brucki et al., 2003; Richards, 2008; Shenkman et al., 2011). However, new studies are necessary to quantify the postural responses when facing external disorders to associate the increase of the LOS with the increase of efficiency in the recovery of balance.

It was expected that the values of the COP and the VOS would be decreased after the intervention, suggesting that the center of mass was being kept within the static support base with smaller and more controlled oscillations, lowering the number and risk of falling (Stel, Smit, Pluijm, & Lips, 2003). This could indicate an improvement in the static balance of the participants in the different sensorial conditions described in this study. These conditions mimic different environments and could appoint a possible decrease in the risk of falling in daily situations that require a static postural control in a stable or unstable surface while some visual stimuli are given and the individual needs to respond with some head movements (Folstein et al., 1975; Hughes et al., 1992; Brucki et al., 2003; Mendes et al., 2005; Richards, 2008; Shenkman et al., 2011).

There was no significant decrease in the COP and the VOS in this study, and it can be explained by the ample motor flotation presented in the PD and by the small sample of this study.

Motor flotation is common in the PD as it progresses. Studies show the appearance of flotations in people with PD, and the results showed that 58% of the people developed motor flotations after an average time of 35 months after the beginning of drug treatment with Levodopa. In this way, the fact that it was not observed a significant change in the COP and the VOS in the study could have happened due to the great motor flotation in people with PD, reflecting the values obtained in the evaluations after the intervention.

The chosen Kinect games for the training developed in this study stimulated upper and lower limbs movements in general, changes of direction, and it also cognitively stimulated the participants, since they were challenged to not only develop motor tasks but also to make decisions based on the virtual environment (Pompeu et al., 2014; Mendes et al., 2015). According to the tasks of each game, the participants had to move fast and develop abilities of postural adjustment that they possibly did not have before. Besides, the participants were challenged to improve their motor performance through intense visual and hearing feedback from the game (Barry et al., 2014). And it can have positively contributed to the increase of the LOS (Folstein et al., 1975; Ebmeier et al., 1990; Hughes et al., 1992; Bennett et al., 1996; Brucki et al., 2003; Mendes et al., 2005; Richards, 2008; Latt et al., 2009; Barry et al., 2014; Conradsson et al., 2015). The increase of the LOS could also be related to the decrease of the muscle and axial rigidity, bradykinesia, and the increase of the articular mobility. In addition, during games, individuals were constantly in movement, contributing to an increase in dynamic balance. Unlike COP and VOS measurements, in which greater static postural control is required, the LOS measurement depends on good dynamic postural control, and its improvement can be related to better dynamic control stimulated by the games.

The postural control depends on these four factors associated: the LOS, static balance, dynamic balance (during the movement), and balance recovered (in external disruption situations of balance) (Ebmeier et al., 1990; Hughes et al., 1992; Bennett et al., 1996; Brucki et al., 2003; Latt et al., 2005; 2009; Barry et al., 2014; Conradsson et al., 2015). Considering that, the results of this study indicate that the training with virtual reality games from the Kinect system improves the area of postural stability, which allows individuals with PD to sway their body with more safety and less risk of accidents, such as falling.

CONCLUSIONS

In conclusion, the results indicate that the training with Kinect Adventures! Games improved the postural control of people with PD by increasing the LOS. Studies with a larger number of participants are necessary to verify if virtual reality games also influence the area and oscillation speed of the COP in different sensorial conditions.

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REFERENCES

Barbosa, M. T., Caramelli, P., Maia, D. P., Cunningham, M. C., Guerra, H. L., ... & Cardoso, F. (2006). Parkinsonism and Parkinson's disease in the elderly: a community-based survey in Brazil (the Bambuí study). *Movement Disorders*, *21*(6), 800-808. https://doi.org/10.1002/mds.20806

Barry, G., Galna, B., & Rochester, L. (2014). The role of exergaming in Parkinson's disease rehabilitation: a systematic review of the evidence *Journal of NeuroEngineering and Rehabilitation*, *11*(33), 1-10. https://doi.org/10.1186/1743-0003-11-33

Bennett, D. A., Beckett, L. A., Murray, A. M., Shannon, K. M., Goetz, C.G., … & Evans, D. A. (1996). Prevalence of parkinsonian signs and associated mortality in a community population of older people. *New England Journal of Medicine*, *334*(2), 71-76. https://doi.org/10.1056/NEJM199601113340202

Benjamin, C. L., & Joseph, K. C. (2001). Epidemiology of Parkinson's disease. *British Columbia Medical Journal*, *43*(3), 133-137.

Brucki, S. M. D., Nitrini, R., Caramelli, P., Bertolucci, P. H. F., & Okamoto, I.H. (2003). Suggestions for utilisation of the mini-mental state examination in Brazil. *Arquivos de Neuro-Psiquiatria*, *61*(3-B), 777-781. https://doi.org/10.1590/S0004-282X2003000500014

Conradsson, D., Löfgren, N., Nero, H., Hagströmer, M., Ståhle, A., … & Franzén, E. (2015). The effects of highly challenging balance training in elderly with Parkinson's disease a randomised controlled trial. *Neurorehabilitation and Neural Repair*, *29*(9), 827-836. https://doi.org/10.1177/1545968314567150

De Rijk, M. C., Tzourio, C., Breteler, M. M. B., Dartigues, J. F., Amaducci, L., ... & Rocca, W. A. (1997). Prevalence of parkinsonism and Parkison's disease in Europe: the Europarkinson col-laborative study. *Journal of Neurology, Neurosurgery, and Psychiatry, 62*(1), 10-15.

Dibble, L. E., Christensen, J., Ballard, D. J., & Foreman, K. B. (2008). Diagnosis of fall risk in Parkinson disease: An analysis of individual and collective clinical balance test interpretation. *Physical Therapy*, *88*(3), 323-332. https://doi.org/10.2522/ptj.20070082

Doná, F., Aquino, C. C., Gazzola, G. M., Borges, V., Silva, S. M., ... & Ferraz, H. B. (2015). Changes in postural control in patients with Parkinson's disease: a posturographic study. *Physiotherapy*, *102*(3), 272-279. http://doi.org/10.1016/j.physio.2015.08.009

Ebmeier, K.P., Calder, S. A., Crawford, J. R., Stewart, L., Besson, J.A., & Mutch, W.J. (1990). Mortality and causes of death in idiopathic Parkinson's disease: results from the Aberdeen whole population study. *Scottish Medical Journal*, *35*(6), 173-175. https://doi.org/10.1177/003693309003500605

Ellis, T., Boudreau, J. K., DeAngelis, T. R., Brown, L. E., Cavanaugh, J. T., … & Dibble, L. E. (2013). Barriers to exercise in people with Parkinson disease. Physical Therapy, *93*(5), 628-636. https://doi.org/10.2522/ptj.20120279

Folstein, M. F., Folstein, S. E., & Mchugh, P. R. (1975). Mini-Mental State – practical method for grading cognitive state of patients for clinician. *Journal of Psychiatric Research*, *12*(3), 189-198. https://doi.org/10.1016/0022-3956(75)90026-6

Fukunaga, J. Y., Quitschal, R. M., Doná, F., Ferraz, H. B., Ganança, M. M., & Caovilla, H. H. (2014). Postural control in Parkinson's disease. *Brazilian Journal of Otorhinolaryngology*, *80*(6), 508-514. https://doi.org/10.1016/j.bjorl.2014.05.032

Galna, B., Jackson, D., Schofield, G., McNaney, R., Webster, M., … & Rochester, L. (2014). Retraining function in people with Parkinson's disease using the Microsoft kinect: game design and pilot testing. *Journal of NeuroEngineering and Rehabilitation*, *11*(60), 1-12. https://doi.org/10.1186/1743-0003-11-60

Hamani, C., & Lozano, A. M. (2003). Physiology and pathophysiology of Parkinson's disease. *Annals of New York Academy of Sciences*, *991*(1), 15-21. https://doi.org/10.1111/j.1749-6632.2003.tb07459.x

Holden, M. K. (2005). Virtual environments for motor rehabilitation: review. *Cyberpsychology & Behavior*, *8*(3), 187-211. https://doi.org/10.1089/cpb.2005.8.187

Hughes, A. J., Daniel, S. E., Kilford, L., & Lees, A. J. (1992). Accuracy of clinical diagnosis of idiopathic Parkinson's disease: a clinico-pathological study of 100 cases. *Journal of Neurology, Neurosurgery, and Psychiatry*, *55*(3), 181-184.

Latt, M. D., Lord, S. R., Morris, J. G., & Fung, V. S. (2009). Clinical and physiological assessments for elucidating falls risk in Parkinson's disease. *Movement Disorders*, *24*(9), 1280-1289. https://doi.org/10.1002/mds.22561

Mancini, M., Rocchi, L., Horak, F. B., & Chari, L. (2008). Effects of Parkinson's disease and Levodopa on functional limits of stability. *Clinical Biomechanics*, *23*(4), 450-458. https://doi.org/10.1016/j.clinbiomech.2007.11.007

Mazzoni, P., & Wexler, N. S. (2009). Parallel explicit and implicit control of reaching. *PLoS ONE*, *4*(10), 1-13. https://doi.org/10.1371/journal.pone.0007557

Menant, J. C., Latt, M. D., Menz, H. B., Fung, V. S., & Lord, S. R. (2011). Postural sway approaches center of mass stability limits in Parkinson's disease. *Movement Disorders*, *26*(4), 637-643. https://doi.org/10.1002/mds.23547

Mendes, F. A. S., Arduini, L., Botelho, A., Cruz, M. B., Santos-Couto-Paz, C. C., & Pompeu, S. M. A. A. (2015). Parkinson's disease patients are able to improve their performance in Xbox Kinect´®s virtual tasks: "a series of cases". *Motricidade*, *11*(3), 68-80. http://doi.org/10.6063/motricidade.3805

Nilsson, M. H., Hariz, G. M., Iwarsson, R., & Hagell, P. (2012). Walking ability is a major contributor to fear of falling in people with Parkinson's disease: implications for rehabilitation. *Parkinson's Disease*, *2012*(1), 1-7. https://doi.org/10.1155/2012/713236

Pedalini, M. E., & Bittar, R. S. M. (1999). Reabilitação vestibular: uma proposta de trabalho. *Pró- fono*, *11*(1), 140-144.

Petzinger, G. M., Fisher, B. E., McEwen, S., Beeler, J. A., Walsh, J. P., Jakowec, M. W. (2013). Exercise-enhanced Neuroplasticity Targeting Motor and Cognitive Circuitry in Parkinson's Disease. *Lancet Neurology*, *12*(7), 716-726. https://doi.org/10.1016/S1474-4422(13)70123-6

Pompeu, J. E., Mendes, F. A., Silva, K. G., Lobo, A. M., Oliveira, T. P., … & Piemonte, M.E.P. (2012). Effect of Nintendo Wii™-based motor and cognitive training on activities of daily living in patients with Parkinson's disease: A randomised clinical trial. *Physiotherapy*, *98*(3), 196-204. https://doi.org/10.1016/j.physio.2012.06.004

Pompeu, J. E., Arduini, L. A., Botelho, A. R., Fonseca, M. B., Pompeu, S. M., ... & Deutsch, J. E. (2014). Feasibility, safety and outcomes of playing Kinect Adventures!™ for people with Parkinson's disease: a pilot study. *Physiotherapy*, *100*(2), 162-168. https://doi.org/10.1016/j.physio.2013.10.003

Redgrave, P., Rodriguez, M., Smith, Y., Rodriguez-Oroz, M. C., Lehericy, S., … & Obeso, J. A. (2010). Goal-directed and habitual control in the basal ganglia:implications for Parkinson's disease. *Nature Reviews Neuroscience*, *11*(11), 760-772. https://doi.org/10.1038/nrn2915

Shenkman, M. L., Clark, K., Xie, T., Kuchibhatla, M., Shinberg, M., & Ray, L. (2011). Spinal movement and performance of standing reach task in participants with and without Parkinson disease. *Physical Therapy*, *81*(8), 1400-1411.

Souza, C. F. M., Almeida, H. C. P., Sousa, J. B., Costa, P. H., Silveira, Y. S. S., & Bezerra, J. C. L. (2001). Parkinson's disease and the Process of Aging Motor: Literature Review. *Revista Neurociências*, *19*(4), 718-723.

Stel, V. S., Smit, J. H., Pluijm, S. M., & Lips, P. (2003). Balance and mobility performance as treatable risk factors for recurrent falling in older persons. *Journal of Clinical Epidemiology*, *56*(7), 659-668. https://doi.org/10.1016/s0895-4356(03)00082-9

Suarez, H., Geisinger, D, Ferreira, E. D., Nogueira, S., Arocena, S., ... & Suarez, A. (2011). Balance in Parkinson's disease changing the visual input. *Brazilian Journal of Otorhinolaryngology*, *77*(5), 651-655. https://doi.org/10.1590/S1808-86942011000500019

Sudhof, T. C., & Malenka, R. C. (2008). Understanding synapses: past, present, and future. *Neuron*, *60*(3), 469-476. https://doi.org/10.1016/j.neuron.2008.10.011

Tamburella, F., Scivoletto, G., Iosa, M., & Molinari, M. (2014). Reliability, validity, and effectiveness of center of pressure parameters in assessing stabilometric platform in subjects with incomplete spinal cord injury: a serial cross-sectional study. *Journal of NeuroEngineering and Rehabilitation, 11*(86), 1-13. https://doi.org/10.1186/1743-0003-11-86

Waterston, J. A., Hawken, M. B., Tanyeri, S., Jantti, P., & Kennard, C. (1993). Influence of sensory manipulation on postural control in Parkinson's disease. *Journal of Neurology, Neurosurgery, and Psychiatry*, *56*(12), 1276-1281. https://doi.org/10.1136/jnnp.56.12.1276

Wood, B. H., Bilclough, J. A., Bowron, A., & Walker, R. W. (2002). Incidence and prediction of falls in Parkinson's disease: a prospective multidisciplinary study. *Journal of Neurology, Neurosurgery, and Psychiatry*, *72*(6), 721-725. https://doi.org/10.1136/jnnp.72.6.721

Wu, T., & Hallett, M. (2007). Neural correlates of dual task performance in patients with Parkinson's disease. *Journal of Neurololy, Neurosurgery and Psychiatry*, *79*(7), 760-766. https://doi.org/10.1136/jnnp.2007.126599