Additional visual information on postural control mechanisms in Parkinson's disease: a pilot study

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https://doi.org/10.20338/bjmb.v18i1.372

HIGHLIGHTS
• Changes in postural control mechanisms due to Parkinson's disease were assessed.
• Sway controlled by central and peripheral mechanisms increased without vision.
• Visual feedback reduced both postural control mechanisms only in healthy adults.
• Visual feedback affected the peripheral postural control in Parkinson's disease.

ABBREVIATIONS
AP   Anterior-posterior
COP   Center of pressure
CE   Closed Eyes
IEPs   Instant Equilibrium Points
OE   Open Eyes
ML   Mediolateral
UPDRS   Unified Parkinson's Disease Rating Scale
PD   Parkinson's disease
VF   Visual Feedback

BACKGROUND: Individuals with Parkinson's disease (PD) have sensorimotor deficits that affect the mechanisms of postural control. Additional visual information effects on postural control mechanisms in PD were unknown.
AIM: To examine the effects of visual information on postural control mechanisms in individuals with PD.
METHOD: Seven individuals with PD and five healthy adults (controls) stood, as quiet as possible, on a force plate for 35 seconds with eyes open, eyes closed, or with additional visual feedback [VF] of the center of pressure (COP). The COP trajectories were calculated in anterior-posterior and mediolateral directions and then decomposed to assess two postural control mechanisms: Rambling (i.e., supraspinal) and Trembling (i.e., peripheral). The amplitude and velocity of COP and Rambling and Trembling components were compared between groups for each visual condition.
RESULTS: The amplitude and velocity of COP and its components were greater in individuals with PD than controls. They increased under closed eyes condition for PD group, but only the Rambling velocity increased in anterior-posterior direction for controls. When additional VF of the COP was provided, individuals with PD presented increased COP and Trembling velocity in mediolateral direction, while healthy individuals presented reduced sway in both directions.
CONCLUSION: Individuals with PD showed greater postural sway and were more affected without visual information than controls. They were not able to use the additional VF to reduce their postural sway as healthy individuals due to changes in sensory integration, causing possible overload in supraspinal processes and compensatory effects in the peripheral postural control mechanisms.

KEYWORDS: Parkinson Disease | Visual information | Feedback visual | Postural control | Sensory feedback

INTRODUCTION

Postural instability affects more than 80% of individuals with Parkinson's disease (PD) [1] and is the main symptom that leads to increased risk of falls [2]. Individuals in early stages of PD already showed postural control impairments, such as larger postural sway in quiet standing than healthy individuals [3,4], although the postural instability is not the initial symptom of PD [5,6,7]. The postural control is assured by an adequate functioning of nervous, sensory (mainly somatosensory, visual, and vestibular systems), and motor systems [8]. Therefore, increased postural sway observed in individuals with PD could be related to impairments in one or more of these systems [9]. In addition, according to a widely accepted theory of postural control, when sensory conditions change, other sensory inputs are dynamically re-weighted, and adequate postural control is a result of a complex multi-sensory integration [9,10]. Hence, it can be hypothesized that individuals with PD also have sensorimotor deficits that affect the mechanisms of postural control [11]. On the other hand, it was suggested that the postural control impairments could be related to a delay in integrating the information from different sensory systems when the condition of one of them is changed [12]. For example, it has been shown that individuals with PD needed more time to change and adjust their postural muscles synergies when the sensory information were manipulated (e.g., closed eyes and additional

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visual information) [13,14].

Several studies reported that individuals with PD have increased dependence on the visual information for postural control [15,16]. Compared to healthy individuals, increased postural sway of individuals with PD was more evident when they stood with eyes closed, mainly in the mediolateral (ML) direction [16] and for postural sway velocity than amplitude [16]. Individuals with PD were also more affected by the visual manipulation when stood inside of a moving room while the ground remained fixed [17]. They showed greater postural sway amplitude in the anterior-posterior (AP) direction, compared to healthy individuals in stationary room condition [17]. These findings suggested that individuals with PD have greater reliance on visual information for postural control and, when absent or unreliable, the other sensory systems have some deficits into compensating it or solving the sensory conflicts in a similar way as healthy individuals. On the other hand, individuals with PD improved their balance (i.e., decreased their postural sway) when real-time, visual feedback (VF) of the trunk and head was provided to them [18]. They also reduced their postural sway when VF of the Center of Pressure (COP) was presented on a monitor screen [19]. Overall, individuals were asked to stay as still as possible while the VF was presented to them. Despite improving the balance, how the information provided by VF affected the postural control mechanisms of individuals with PD is not fully understood.

The VF effects on the postural control mechanisms were only investigated when healthy individuals were asked to stay as still as possible using the visual information of the COP position [20]. For this, a stabilogram decomposition method, called Rambling-Trembling, was used [21,22]. Based on this method, the COP trajectory is decomposed in two components: one is the Rambling, which is associated with central processes of postural control, while the second is the Trembling, which is associated with the peripheral mechanisms [21,22,23]. Both components of postural sway were affected by the VF of COP, but while the Rambling increased when VF was provided, the Trembling reduced. According to the authors [20], these findings suggested that an increase in muscle activation level is due to associated mechanical factors and segmental reflex effects [20]. Recently, this method was used to examine the postural control mechanisms in individuals with PD during quiet standing under open eyes condition [11]. The results revealed that individuals with PD present greater amplitude and velocity of COP, Rambling, and Trembling than healthy individuals, mainly for AP amplitude and AP and ML velocity. The authors suggested that the changes in postural control in individuals with PD were related to both central and peripheral control mechanisms [11]. In particular, the effects on Rambling trajectory may be related to impaired sensory integration while the effects on Trembling could be due to delayed sensorimotor feedback process needed to stabilize the upright posture [11]. However, the participants were assessed only with eyes open and changes on the postural control mechanisms due to PD may be more evident in the absence of visual information (i.e., closed eyes). The effects of additional VF on the postural control mechanisms may contribute to the understanding about the sensorimotor deficits, such as delayed sensory integration and increased visual reliance, to maintain the upright standing in individuals with PD.

Therefore, the current study aimed to examine the effects of visual information on the trajectory of COP, and two components of postural control mechanisms, Rambling, and Trembling, in individuals with PD. The visual information was manipulated in three conditions asking participants to fix their gaze to a stationary target, close their eyes, or try to minimize the movement of the target representing the VF of the COP. Our first hypothesis was that the amplitude and velocity of the COP, Rambling, and Trembling would increase when the visual information was absent (i.e., closed eyes condition) and would reduce with VF compared to open eyes condition. A second hypothesis was that Rambling would be more affected than Trembling, mainly in VF condition, because PD affects the sensory integration [13]. The results of this study will contribute with the understanding about the postural control mechanisms of individuals with PD and the influence of the visual information in the sensory integration for postural control. The findings of the current study may give support for future interventions with the aim of manipulating the postural control mechanisms for the balance rehabilitation of individuals with PD.

METHOD

Participants

Twelve individuals, 45–79 years old, participated in this study. Seven of them were PD individuals (3 females) assessed in 'On' phase of their medication. The PD group presented the following characteristics: mean age (±S.D.) of 64.86 (± 11) years, height of 1.62 (± 0.11) m, and body mass of 73 (± 9.3) kg. The PD individuals were assessed using the Unified Parkinson's Disease Rating Scale part III (UPDRS-III) [24] and had an average score of 38.50 (± 12.13). The control group was composed by five individuals without known neurological disorders or musculoskeletal and joint disorders [all females, 60.8 (± 9.34) years; height of 1.59 (± 0.08) m; and body mass 71.20 (± 2.19) kg]. All individuals participated voluntarily and gave written informed consent according to the protocol approved by the local ethics committee prior their participation.

Experimental Procedures

Participants were instructed to stand, barefoot, in a comfortable position, with the feet approximately at shoulder width on a force plate (AMTI OR6-7, Watertown-MA, OR6-7, 50.8 cm x 46.4 cm). The feet position was marked on the force plate to be reproduced across trials. The force plate data were acquired at a sampling frequency of 100 Hz using a custom code written in LabView 2010 (National Instruments Corp., Norman, OK, USA). Participants were asked to stay as still as possible, for 35 seconds, in three visual

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conditions: a) keeping their eyes closed (closed eyes condition, CE); b) fixing their gaze to a stationary target (open eyes condition, OE); and c) trying to minimize the movement of a target by reducing their body sway (explicit information of it was provided in this additional visual feedback condition, VF). In OE and VF trials, the target was presented as a black, 1-cm diameter circle on a white background in the center of the 32" touchscreen monitor (ELO, Milpitas-CA) positioned at participant eye's height and 1m in front of the participant (Figure 1). The VF condition was like that used in previous studies [25,26,27]. In this condition, the target could move up or down according to the real-time instantaneous changes of the COP position in the AP direction. There was no magnification factor added to the target movements and participants were aware that the target motion was related to their body sway. They also had one minute of practice in the VF on the screen before the beginning of the experimental trials. Participants performed six trials, two trials for each condition, in a randomized order and rest intervals between two trials were allowed.
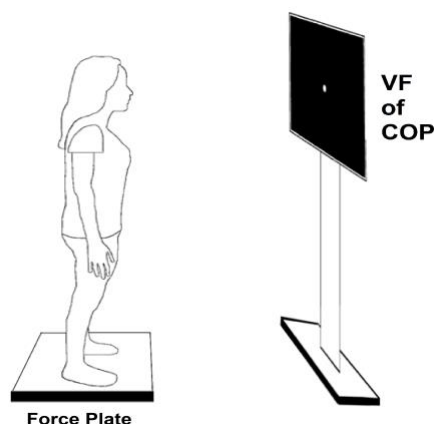

Figure 1. Participants' position on the force plate. Note: VF: Visual Feedback; COP: Center of Pressure.

Data Analyses

Data analyses were developed in a Matlab R2022b routine. First, forces and moments of force data were filtered with a low-pass Butterworth filter of 10Hz and then used to calculate the COP trajectories in AP and ML directions (COP$_{AP}$ and COP$_{ML}$, respectively) as:

$$COP_{AP} = \frac{(-h * Fx) - My}{Fz} \quad COP_{ML} = \frac{(-h * Fy) - Mx}{Fz}$$

where h is the height of the base of support, F$_x$, the horizontal force in AP direction, F$_y$, the horizontal force in ML direction, M$_y$, the ML moment, M$_x$, the AP moment, and F$_z$, the vertical reaction force. Next, five seconds of the trials were excluded by removing the first and last 2.5 seconds of the trial. Analysis of postural control mechanisms was performed by decomposing COP trajectory in Rambling and Trembling components [21,22]. First, the instant equilibrium points (IEPs) were identified when the horizontal force was zero. Then, COP position was determined in these IEPs and Rambling and Trembling trajectories were calculated based on these values. Rambling trajectory was defined by the interpolation of these COP values using a cubic spline function. Trembling trajectory was calculated by the difference between Rambling and COP trajectories. Mean amplitude of COP, Rambling, and Trembling were calculated as the root mean square of each time-series. COP, Rambling, and Trembling mean velocity were computed dividing the path length by the time-series duration (here 30s as we removed 5s of the analysis). The mean amplitude and velocity were calculated for each trial and averaged across trials for the statistical analyses.

Statistical Analyses

Statistical analyses were performed using IBM SPSS software, version 21 for Windows. Considering the sample size, non-parametric tests were used for data analysis. First, group comparisons were run for the OE condition. Then, changes on the CE and VF conditions related to OE condition were computed and compared between groups. All group comparisons were run using Mann-Whitney test. Microsoft Excel® was used to calculate the effect size. The effect size (r) was calculated by following formula: $r = \frac{|z|}{\sqrt{n}}$. The Z score is mapping the data in a distribution, and the N value represents the number of participants. A small effect was considered less than 0.3, a medium effect for values between 0.3 to 0.5, and a larger effect for greater than 0.5 [28]. To test our hypothesis, the Wilcoxon test was also run comparing the values under CE or VF conditions normalized by OE condition with a single value of 100% (considered the OE condition). The significance level was set at $p < 0.05$.

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RESULTS

All participants were able to stand under OE, CE, and VF conditions. The results of amplitude and velocity of COP, Rambling, and Trembling trajectories in AP and ML directions in the OE condition are presented in figure 2. In this condition, individuals with PD presented a greater COP and Rambling amplitude than controls only in ML direction [U=4, p=0.03; r=0.63 and U=4, p=0.03; r=0.63, respectively]. The velocity was greater for individuals with PD for COP in AP direction [U=3, p=0.018; r=0.68] and for Rambling in AP [U<0.001, p=0.003; r=0.82] and ML [U=2, p=0.010; r=0.73] directions compared to control individuals. There was a trend (p=0.073) of increased COP amplitude in AP direction and increased velocity for COP and Trembling components in both directions.

Effect of *absent* visual information

To verify whether the absence of visual information affected the amplitude and velocity of COP, Rambling, and Trembling in the CE condition, the values were normalized by the OE condition. The results in percentage are presented in table 1. When the visual information was removed (i.e., CE condition) the COP velocity increased for both directions for PD (p=0.018 and p=0.043, respectively, AP and ML directions) and controls (p=0.043 and p=0.043, respectively, AP and ML directions) compared to 100% (representing OE condition). In addition, the increase in the amplitude of COP was greater in individuals with PD than controls in the ML direction (p=0.043) and a trend in AP direction (p=0.063).

Table 1. Median and median deviations of both groups for AP and ML directions, amplitude, and velocity of COP, Rambling, and Trembling.

Conditions	PD group (n=7)		Control group (n=5)	
Closed Eyes	**AP**	**ML**	**AP**	**ML**
COP				
Amplitude (cm)	141.2 (17.4)	155.8 (26.3)*	128.7 (32.1)	149.6 (29.5)
Velocity (cm/s)	139.5 (19.7)&	114.6 (52.9)&	149.7 (27.9)&	138.7 (25.1)&
Rambling				
Amplitude (cm)	147.1 (14.7)&,*	129.1 (23.3)	119.2 (11.2)	127 (40.3)
Velocity (cm/s)	124.4 (27.9)	124 (37.9)	147 (25.7)&	124.9 (32.6)
Trembling				
Amplitude (cm)	134.8 (29.1)&	122.1 (50.6)	132.7 (32.1)	120.6 (41.5)
Velocity (cm/s)	166.1 (19.7)&	127.1 (56.2)	146.2 (30.1)	132.1 (36.4)
VF	**AP**	**ML**	**AP**	**ML**
COP				
Amplitude (cm)	118.8 (28.4)	108.7 (24.2)	79.1 (16.4)	110.3 (23.3)
Velocity (cm/s)	107 (6.7)	116.8 (9.5)&,*	97.5 (4.1)	90.2 (1.4)&
Rambling				
Amplitude (cm)	112.8 (20.2)	101.3 (22.9)	81.5 (14.8)	86.7 (8.4)
Velocity (cm/s)	91.6 (14.7)	116.8 (16.9)	109.6 (9.7)	88.5 (5.8)&
Trembling				
Amplitude (cm)	109.5 (21.3)*	115 (30)	89.5 (7.8)&	85.4 (6.3)
Velocity (cm/s)	98.4 (21.7)	117.3 (10.6)&,*	91.9 (8.9)	91 (5.2)&

Note: PD: Parkinson's disease; AP: anterior-posterior; ML: mediolateral; COP: Center of pressure. *p<0.05 for group comparison. &p<0.05 for comparison with 100%.

The CE condition also affected the Rambling and Trembling amplitudes (p=0.018 and p=0.028, respectively) in AP direction for individuals with PD. The Trembling velocity in AP direction also increased in the CE condition (p=0.018). For controls, only the Rambling velocity in AP direction (p=0.043) was affected by the absence of the visual information. There was only significant difference between groups in the Rambling amplitude in AP direction [U=2, p=0.01; r=0.73]. Individuals with PD increased more the Rambling amplitude with CE than controls (table 1).

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Effect of *additional* visual information

When additional visual information was provided, individuals with PD increased the COP and Trembling velocity in ML direction (p=0.028 and p=0.028, respectively). Individuals of the control group reduced the velocity of COP and its components in the ML direction and the Trembling amplitude in AP direction in the VF condition (all p=0.043). Individuals with PD had greater COP and Trembling velocity in ML direction [all U<0.001, p=0.003; r=0.82] and Trembling amplitude in AP direction [U=4, p=0.03; r=0.63] compared to control group.
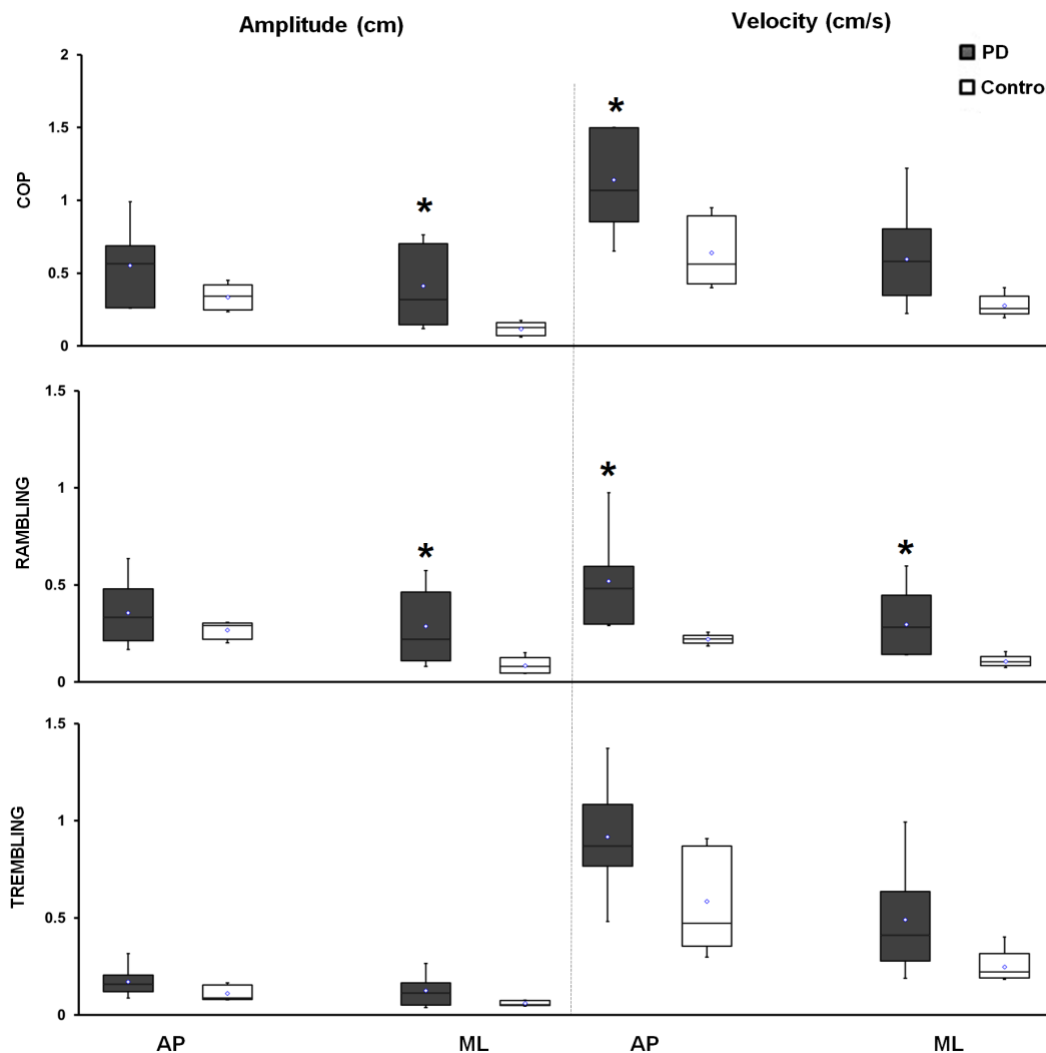
Figure 2. Boxplot with values of amplitude and velocity of COP, Rambling and Trembling for AP and ML directions, of the OE condition for both groups. Note: COP: Center of pressure; PD: Parkinson's disease; AP: Anterior-posterior; ML: Mediolateral. * p<0.05.

DISCUSSION

Individuals with PD present sensorimotor deficits [9] that can impair their postural control. It has also been suggested that they have increased reliance on the visual information [15,16] during upright standing. We examined how the visual information (when it is absent or when additional VF of COP is provided) affects the postural control mechanisms in individuals with PD. Overall, individuals with PD presented greater COP amplitude and velocity, mainly in ML direction and with eyes closed. These results support part of our first hypothesis and corroborate with previous studies [15,16,29] that observed greater effect of absent visual information on the COP variables in individuals with PD. They also confirm previous findings that the increased postural sway in individuals with PD is due to impairments in both supraspinal and peripheral postural sway mechanisms (respectively, observed by changes in Rambling and Trembling components of COP) [11]. We extended the findings from Costa and collaborators [11] showing increased Rambling component when the visual information was removed (CE condition) and increased Trembling component with additional visual information of the COP (VF condition)

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"Manipulation of sensory information on postural control
performance of children, young and older adults"

for individuals with PD compared to controls. Interestingly, this later effect was observed because, contrary to healthy individuals, those with PD were not able to use the VF of the COP to reduce their postural sway. They showed greater COP velocity in the VF condition than when they did not receive it (i.e., OE condition). Healthy individuals, however, presented a COP velocity approximately 10% smaller than in OE condition, corroborating with a previous study that they take advantage of the VF [27].

Based on previous studies, we expected that if individuals with PD are more dependent on visual information to maintain the posture [15,16], their postural stability should increase in the VF condition. This hypothesis was based on the fact that VF of the COP has been described as a strategy to improve balance [19] and gait [30] of individuals with PD. Our results were opposite to our expectations and went against, in part, the predictions of our first hypothesis. Individuals with PD increased the COP velocity when they received the VF compared to the OE condition corroborating with previous study that also observed that PD did not use the real-time VF to reduce their sway [31]. There is a two-fold explanation for the increased postural sway in our study: a difficulty in integrating the information provided by the VF [9,32] or a delay in the sensory integration as reported in previous study [13]. Regarding the first explanation, it was observed that when visual information was restored after a period of time with it removed, individuals with PD did not improve their postural stability during quiet standing. This finding suggested the existence of central deficits to reorganize the sensory information to control their postural sway [32]. If that is the case in our study, increased amplitude and velocity of the Rambling component should be observed under VF compared to OE condition. However, the VF effects were observed mainly in the Trembling component of postural sway, which is related to the changes in the properties of the mechanical and neural structures implementing the supraspinal control signals [20]. Hence, the hypothesis of difficulty in integrating the information provided by the VF may be refuted and corroborates with previous study [13].

It is possible that an overload in supraspinal postural control mechanisms [31] had cause a delay to integrate the information provided by the VF and then compensatory effects are required by the peripheral postural control mechanisms. A delay in compensating the postural changes in different visual conditions has been reported [12]. For example, when visual condition changed from EC to EO individuals with PD showed a delay in changing their balance strategy [12]. Individuals with PD also showed impaired neuromuscular adaptation and a delayed ability to become accustomed to the postural response [33] after repeated exposure to postural perturbation.

The current findings showed that, although previous studies reported that individuals with PD have increased dependence on the visual information for postural control [15,16], they also have sensory integration deficits that may be responsible for the inability of taking advantage of VF [9,32]. Because PD is characterized by dopamine deficiency in substantia nigra, and the substantia nigra with caudate nucleus have the vestibular, visual, and somatosensory neurons [34], it was assumed that the velocity of the integration of the sensory information is impaired [12,13].

Furthermore, another alternative hypothesis is that the VF effects can be influenced by task instruction. In the current study, the target motion was associated with individual's body sway. The instruction for maintaining the target position as still as possible may require the cognitive component (i.e., language and attentional component) [35], which is processed by supraspinal systems and can contribute to the overload mentioned earlier. In fact, it has been suggested that cognitive disorder is associated with increased postural sway and, consequently, increased risk of falls [36]. Based on these facts, our second hypothesis that Rambling should be more affected than Trembling, mainly in VF condition, was refuted. The additional visual information provided by VF did not affect the Rambling trajectory in individuals with PD; but increased the COP and Trembling variables mainly in the ML direction. The influence of VF of COP on the Trembling component suggests that peripheral rather than suprapostural mechanisms were changed in PD. It is possible to relate this with increased muscle contraction, hypertonicity, or rigidity [37], due to the task instruction to stay as still as possible, influencing more the peripheral postural control mechanisms [38]. Overall, these findings corroborate with the information that individuals with PD have difficulty to use the additional visual information to improve postural stability [31,33]. Future studies should investigate whether individuals with more advanced PD and with different clinical characteristic (e.g., freezing of gait) have different responses to VF of the COP.

Study limitation

The analysis of the present study was performed from previous collected data with limited number of participants. Future studies are needed to examine the additional visual information effects in a larger sample of individuals with PD, with possible influence of disease stage and different clinical characteristics. Because only few trials were assessed, it is possible that individuals with PD needed more trials to adequately take advantage of the VF [13,14].

CONCLUSION

In summary, individuals with PD oscillate more than healthy individuals. With the absence of visual information, both groups increased their postural sway. On the other hand, the postural control mechanisms of healthy individuals were positively affected with additional VF, but not individuals with PD. VF increased the Trembling component related to the peripheral control mechanisms in individuals with PD. This indicated that when sensory information is manipulated, individuals with PD may need more time to reorganize the sensory information and compensate the effects in peripheral mechanisms.

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"Manipulation of sensory information on postural control
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ACKNOWLEDGMENTS