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Parkinson's patients delay fixations when circumventing an obstacle and performing a dual cognitive task

Vinicius Alota Ignacio Pereira[a], Paula Favaro Polastri[b], Lucas Simieli[a], Shirley Rietdyk[c], Luis Felipe Itikawa Imaizumi[a], Gabriel Felipe Moretto[a], Tiago Penedo[a], Sérgio Tosi Rodrigues[b], Fabio Augusto Barbieri[a,*]

[a] São Paulo State University (UNESP), Human Movement Research Laboratory (MOVI-LAB), Graduate Program in Movement Science, Department of Physical Education, Bauru, SP, Brazil
[b] São Paulo State University (UNESP), Laboratory of Information, Vision and Action (LIVIA), Graduate Program in Movement Science, Department of Physical Education, Bauru, SP, Brazil
[c] Department of Health and Kinesiology, Purdue University, West Lafayette, IN, USA

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ABSTRACT

Background: People with Parkinson's disease (PD) do not differ from neurologically healthy individuals in obstacle circumvention during walking, therefore they are able to use visual feedback adequately to control motor behavior in this task. However, individuals are often distracted by the secondary task when circumventing an obstacle. An increased cognitive load can require prolonged gaze fixation time on a location of interest to compensate for longer information processing duration.
Research question: To investigate the effects of cognitive dual tasking (DT) on gaze behavior during waking with obstacle circumvention in people with PD and control group, and to determine the impact of gaze behavior on motor strategy.
Methods: Fifteen individuals with PD (PD-group) and 15 neurologically healthy individuals walked at a self-selected speed over a walkway and circumvented an obstacle centered in the walkway. The experimental conditions (5 trials each one) included obstacle circumvention without DT (OC) and obstacle circumvention with DT (OCDT). In the cognitive task, the participant mentally counted the number of times a target number appeared in an audio recording. We analyzed gaze behavior (i.e. number of gaze fixations and duration on the ground and obstacle), standard gait measures and DT cost. Two-way ANOVAs were completed for gait parameters and moment of fixation.
Results: There was no significant difference in DT cost between groups and no obstacle contacts. The participants performed a longer mean duration of fixations on the ground during OCDT compared to OC. Group x condition interactions indicated that the PD-group delayed the obstacle fixation relative to the NHI for OCDT ($p < 0.001$) and presented greater medial-lateral body clearance ($p < 0.001$) and longer double support time ($p < 0.001$) during OCDT compared to OC.
Significance: The results of this study suggest that deficits in locomotion during DT in PD-group may be caused, at least in part, by a reduced ability to fixate gaze at appropriate times during walking.

1. Introduction

Visual feedback is important for successful locomotor adaptations, as demonstrated by studies on targeting and other protocols [1]. Vision provides information about environmental surroundings and characteristics of objects, such as details (height, size, color, etc.) and the position of an obstacle, and about the body relative to the environment, such as fixating the foot while deliberately stepping on targets [2], which facilitates adequate motor adjustments. Specifically for obstacle circumvention during walking, the information gained from obstacle fixations is used to control movement in feedforward and online modes [3–5], which is directly related to success in the motor task and dependent on the complexity of the task [1,2]. However, movement disorders, such as Parkinson's disease (PD), may compromise the ability to

* Corresponding author at: Universidade Estadual Paulista "Júlio de Mesquita Filho" (São Paulo State University), UNESP – FC – Bauru, Human Movement Research Laboratory (MOVI-LAB), Department of Physical Education, Av. Eng. Luiz Edmundo Carrijo Coube, 14-01, CEP: 17033-360, Bauru, SP, Brazil.
E-mail address: fabio.barbieri@unesp.br (F.A. Barbieri).

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visually detect the obstacle position, which in turn impairs obstacle avoidance and balance recovery after circumventing the obstacle [1].

PD compromises vision, including impaired visuo-spatial ability [6], impaired visual sampling [7], and reduced ability to fixate environmental features at appropriate moments in the action sequence [8]. Compromised vision results in higher reliance on visual feedback and impairs adaptive locomotor behavior in obstacle avoidance tasks [9]. However, people with PD do not differ from controls in obstacle circumvention during walking [3], therefore they are able to use visual feedback adequately to control motor behavior in this task. This fact may be related to less stringent requirement on foot placement for obstacle circumvention during walking versus protocols with foot targeting, obstacle crossing and stairs. However, impaired behavior may also be related to compromised executive function in people with PD. Declines in executive cognitive functioning require prolonged gaze fixation time on a location of interest [10] during challenging walking, such as obstacle circumvention, to compensate for longer information processing duration [11].

Declines in cognitive function and the ability to appropriately switch attention between environmental hazards, as happens in people with PD [7], may underlie maladaptive gaze behavior, which can cause a higher number of falls [12]. People with PD shift to a more conscious control of walking, and as a result, there is a greater demand for attentional resources to control the walking compared to neurologically healthy individuals [13]. This attempt to consciously control walking and complete a secondary cognitive task has been found to overload conscious control resources, causing a substantial deterioration in gait in people with PD. Although obstacle circumvention is performed regularly during daily activities, individuals are often distracted by other physical or cognitive activity such as thinking, memorizing information or talking [14]. This is characterized as dual-tasking (DT) paradigm [15] and requires proper interaction and integration of mobility and cognitive capacity [14], which can change the information priority, especially related to gait control/visual feedback and/or success on the cognitive task. Relevant visual feedback while walking improved gait control and decreased processing demands required to control gait in PD [9,16]. For example, people with PD attenuates saccadic frequency when competition for cognitive control increases during walking to perform fixations on obstacle and ground [7]. Therefore, this study will extend current knowledge about the effect of dual task on gaze behavior in people with PD when accurate foot placement is not as tightly controlled.

Thus, the purpose of the study was to investigate the effects of cognitive DT on gaze behavior during waking with obstacle circumvention in people with PD and neurologically healthy individuals (control group), and to determine the impact of gaze behavior on motor strategy (spatial-temporal parameters). We hypothesized that walking with DT would increase the number and duration of fixations on the obstacle and ground in people with PD. We also hypothesized that the temporal patterns of obstacle and ground fixations would be modified in people with PD. In addition, we hypothesized that people with PD would have more cognitive errors in the DT compared to control group. To compensate for the compromised gaze behavior, people with PD would improve stability (larger step width and double support time) and safety (higher medial-lateral and anterior-posterior distance to the obstacle), and reduce stride length and step velocity during DT.

2. Method

The study included 30 individuals: 15 individuals with idiopathic PD (PD group - 5 males) and 15 neurologically healthy participants matched for sex, age, height and weight (control group) (Table 1). A neurologist evaluated and diagnosed people with PD according to the London Brain Bank [17]. The study was approved by the University local Ethics Committee (#45435615.7.1001.5398). All participants signed a written consent according to the Declaration of Helsinki.

Exclusion criteria included: age below 50 years, score below 24 in Mini-Mental State Examination, any visual or auditory deficit and orthopaedic or musculoskeletal disease that would affect the ability to complete the experimental protocol, and the presence of other neurodegenerative disease (i.e. Alzheimer disease). Inclusion criteria for people with PD included: taking anti-parkinsonian medication with no change the medication in the last two months and Hoehn and Yahr stage $\leq$ 3. At testing, the PD group was optimally medicated: Approximately one-hour post dopaminergic medications.

Individuals with PD were evaluated by a trained examiner through anamneses, the motor portion of the Movement Disorder Society revised Unified Parkinson's Disease Rating Scale – UPDRS, which assessed the PD symptoms and signs (a high score indicates greater impairment) [18], and the Hoehn and Yahr score, which evaluated PD severity [19]. Cognitive scores of both groups were evaluated through the Mini-Mental State Examination, which is a brief 30-point questionnaire, in which values up to 24 points are considered as mentally "intact" [20].

2.1. Protocol

Participants walked at a self-selected speed over a walkway (8.5×3.5 m, length x width) and circumvented an obstacle (0.35 m x 1.30 m, diameter x height) positioned 5 m from the start and centered in the walkway [3,4]. At the start position, the participant was in line with the obstacle and self-selected the side to circumvent the obstacle. Two experimental conditions included: obstacle circumvention without DT (OC) and obstacle circumvention with concomitant DT (OCDT). Five trials were collected for each walking condition (total 10 trials), and trials were randomized.

In the cognitive task, the participant mentally counted the number of times a target number appeared in an audio recording. They were instructed not to count out loud or use their fingers. The audio recording was a series of single digit numbers, lasting approximately 12 s, with approximately 10 numbers presented at varying frequency to prevent use as auditory cue). Participants were given a new target number at the beginning of each trial, and reported the count at the end of walkway. The target number was randomized between trials, and the number of times that the target number appeared in the sequence was random and ranged from 1 to 10.

2.2. Data acquisition and analysis

Gaze behavior (Mobile Eye-5 glasses, ASL, Bedford, MA, USA) was collected at 60 Hz and analyzed with ASL Results Plus software. The eye tracker was calibrated with nine points, and calibration was checked periodically between trials. Gaze fixation was defined as when two times the point of gaze fixation (95% confidence interval) was less than one degree of visual angle (horizontal and vertical) over 99 ms [3,4]. Areas of interest included the obstacle and the ground [3,4].

Kinematic data were obtained from 8 cameras Vicon Motion System® (Bonita System Cameras) at 100 Hz. The kinematic parameters were analyzed in two phases of the trials: approaching phase (final stride before the obstacle circumvention) and circumvention phase (stride during obstacle circumvention) [8 - see Fig. 1]. Thirty-nine passive reflective markers were placed according to the Plug-in-Gait Full Body model (Vicon) and five markers were placed on the obstacle. The kinematic data were filtered using a 5th order low-pass digital Butterworth filter (zero-lag) with a cutoff frequency of 6 Hz. Nexus software (Vicon) calculated the center of mass coordinates based on a 15-segment model. The gait parameters were processed with Matlab (version R2016b).

The gaze parameters included the following: number of fixations [3,4] was the total number of fixations during the trial in each area of interest, expressed as percent of total fixations, mean duration of the fixations [3,4] was the average duration in each area of interest for each trial, time of fixations [3,4] was the summed value of each fixation on

Table 1
Clinical features, characteristics and DT performance in both PD group and control group. AP - approaching phase; CP – circumvention phase. No statistically significant differences were observed. UPDRS - Unified Parkinson's Disease Rating Scale; H&Y - Hoehn and Yahr; MMSE - Mini-Mental State Examination.

			Control group	PD group	p-values (F values)
Age (years)			65.3 ± 6.8	68.5 ± 5.8	–
Body Mass (kg)			69.4 ± 15.7	69.1 ± 10.1	–
Height (m)			1.59 ± 0.08	1.60 ± 0.06	–
Disease duration (months)			–	72 ± 24	–
UPDRS-motor portion (pts)			–	24.7 ± 11.8	–
H&Y (score)			–	1.9 ± 0.6	–
MMSE (pts)			27.2 ± 1.4	28.0 ± 2.5	p = 0.67 ($F_{2,42}$ = 0.39)
DT performance (number of errors)			9	15	p = 0.44 ($F_{1,28}$ = 0.59)
DT cost (%)	**Stride velocity**	**AP**	8.0	10.8	p = 0.91 ($F_{1,28}$ = 0.01)
		CP	9.0	10.2	p = 0.38 ($F_{1,28}$ = 0.76)
	Stride length	**AP**	2.5	5.2	p = 0.68 ($F_{1,28}$ = 0.16)
		CP	4.1	10.5	p = 0.71 ($F_{1,28}$ = 0.14)

each area of interest, expressed as percent of travel time, and moment of fixation on ground and obstacle areas was the duration between the fixation time on ground or obstacle and the time that the participant was beside the obstacle. The travel time analyzed in each trial for gaze parameters was from the start of trial to the frame that the participant was in the side of the obstacle.

Standard gait measures were assessed: stride length, stride width, stride duration, stride velocity, and double support time. Two measures of body clearance were included: medial-lateral body clearance [3–5] was the largest medial-lateral distance of the center of mass to the obstacle during obstacle circumvention phase, and anterior-posterior body clearance [3,4] was the distance at which participants started to circumvent the obstacle, or where they deviated from the anterior-posterior path.

Changes to performance were quantified with DT measures: DT cost [13] ((([(dual task − single task)/single task] × 100) for stride length and speed), and DT performance: number of errors (incorrect answer for the target number) during cognitive DT.

2.3. Statistical analysis

Data were normally distributed and parametric statistics were used. One-way ANOVAs with group (2 levels: PD and control) were used to identify differences in cognitive status, number of errors in DT, and DT cost. Two-way ANOVAs, group (2 levels: PD and control) by condition (2 levels: OC and OCDT), with repeated measures for the last one, were completed for gait parameters and moment of fixation; these ANOVAs were completed separately for the approach and circumvention phases. Three-way ANOVAs, group by condition by area of interest (2 levels: ground and obstacle), with repeated measures for the last two, were completed for the other gaze parameters. Tukey post hoc tests were used when a significant main or interaction effect was found. P-value was set to ≤0.05 and the dependent variables of interest were statistically analyzed with SPSS 21.0 for Windows®.

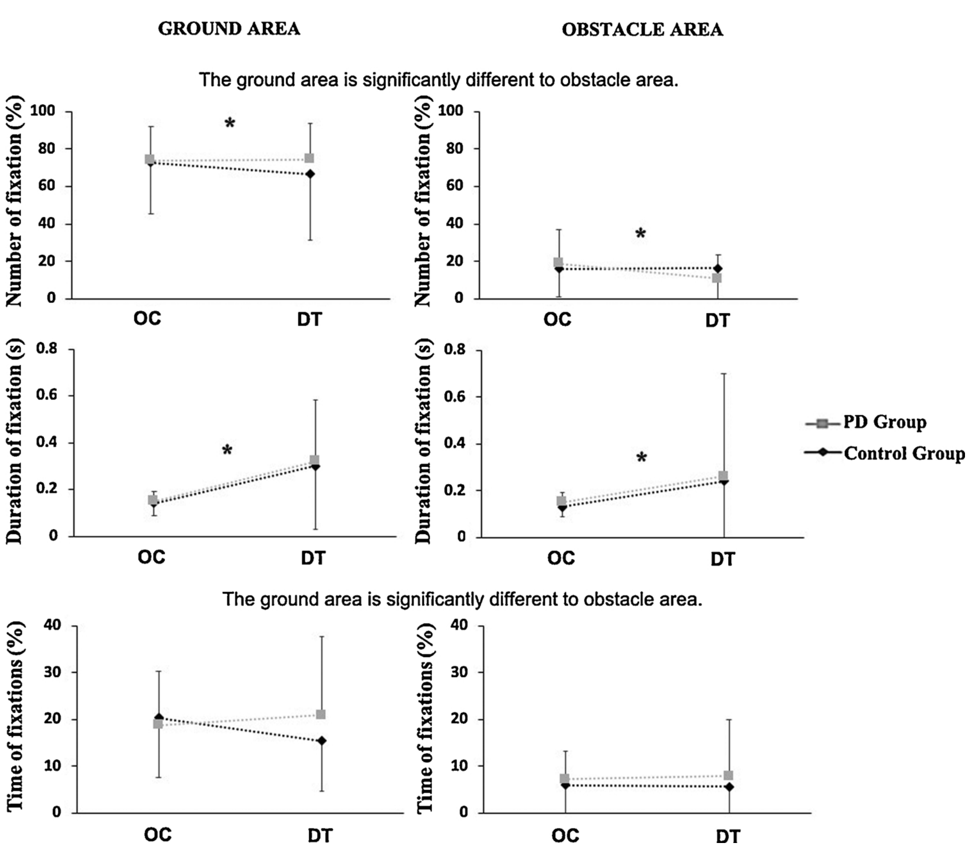

Fig. 1. Means and standard deviations of the gaze parameters according to areas of interest on obstacle circumvention without (OC) and with DT (DT) in the PD group (PD) and control group (CG). Error bars represent standard deviation. Gray dotted lines with box are the PD results, and black dotted lines with diamonds are the CG results. Asterisk (*) indicates significant difference between conditions. No group differences were observed for these measures.

Table 2
ANOVAs results for the main effects of group, condition, area of interest (AOI) and interactions (group x condition and condition x AOI. The other interactions were not significant. PD – PD group; CG – control group; OC – obstacle circumvention without DT; DT – obstacle circumvention with DT; GR – ground; OB – obstacle; AP – approaching phase; CP – circumvention phase.

		Group	Condition	AOI	Group X Condition	Condition X AOI
Gaze parameters						
number of fixations	–	$F_{1,28} = 1.01$, $p = 0.32$	$F_{1,28} = 6.17$, **$p < 0.01$** ***DT < OC***	$F_{1,28} = 49.40$, **$p < 0.001$**	$F_{1,28} = 0.02$, $p = 0.96$	$F_{1,28} = 0.34$, $p = 0.56$
mean duration of the fixations	–	$F_{1,28} = 0.76$, $p = 0.78$	$F_{1,28} = 6.06$, **$p < 0.02$** ***DT > OC***	$F_{1,28} = 1.15$, $p = 0.29$	$F_{1,28} = 0.02$, $p = 0.96$	$F_{1,28} = 2.93$, **$p < 0.04$** ***DT > OC:GR(p < 0.004)***
time of fixations	–	$F_{1,28} = 0.90$, $p = 0.35$	$F_{1,28} = 0.13$, $p = 0.74$	$F_{1,28} = 33.01$, **$p < 0.001$** ***GR > OB***	$F_{1,28} = 1.46$, $p = 0.23$	$F_{1,28} = 0.14$, $p = 0.71$
moment of fixation on ground area	–	$F_{1,28} = 3.92$, $p = 0.06$	$F_{1,28} = 0.04$, $p = 0.82$	–	$F_{1,28} = 3.88$, **$p < 0.05$** ***PD > CG:OC(p < 0.005)***	–
moment of fixation on obstacle area	–	$F_{1,28} = 2.80$, $p = 0.10$	$F_{1,28} = 0.57$, $p = 0.45$	–	$F_{1,28} = 16.70$, **$p < 0.001$** ***PD < CG:DT(p < 0.001)/DT < OC:PD(p < 0.002)/ DT > OC:CG(p < 0.02)***	–
Spatial-temporal parameters						
medial-lateral body clearance	–	$F_{2,27} = 16.37$, **$p < 0.002$** ***PD > CG***	$F_{1,28} = 15.54$, **$p < 0.001$** ***DT > OC***	–	$F_{1,28} = 12.82$, **$p < 0.001$** ***DT > OC:PD(p < 0.001)/ PD > CG:DT(p < 0.001)***	–
anterior-posterior body clearance	–	$F_{1,28} = 0.54$, $p = 0.81$	$F_{1,28} = 21.92$, **$p < 0.001$** ***DT > OC***	–	$F_{1,28} = 0.04$, $p = 0.83$	–
stride length	**AP**	$F_{1,28} = 13.23$, **$p < 0.001$** ***PD < CG***	$F_{1,28} = 5.36$, **$p < 0.02$** ***DT > OC***	–	$F_{1,28} = 0.10$, $p = 0.74$	–
	CP	$F_{1,28} = 19.06$, **$p < 0.001$** ***PD < CG***	$F_{1,28} = 0.51$, $p < 0.47$	–	$F_{1,28} = 0.06$, $p = 0.80$	–
stride width	**AP**	$F_{1,28} = 0.36$, $p = 0.55$	$F_{1,28} = 1.28$, $p = 0.26$	–	$F_{1,28} = 1.50$, $p = 0.23$	–
	CP	$F_{1,28} = 0.09$, $p = 0.85$	$F_{1,28} = 0.05$, $p = 0.82$	–	$F_{1,28} = 0.50$, $p = 0.48$	–
stride duration	**AP**	$F_{1,28} = 0.01$, $p = 0.91$	$F_{1,28} = 0.58$, $p = 0.45$	–	$F_{1,28} = 0.003$, $p = 0.95$	–
	CP	$F_{1,28} = 0.32$, $p = 0.57$	$F_{1,28} = 0.44$, $p = 0.51$	–	$F_{1,28} = 0.56$, $p = 0.45$	–
stride velocity	**AP**	$F_{1,28} = 9.56$, **$p < 0.004$** ***PD < CG***	$F_{1,28} = 1.33$, $p = 0.25$	–	$F_{1,28} = 0.15$, $p = 0.69$	–
	CP	$F_{1,28} = 8.00$, **$p < 0.009$** ***PD < CG***	$F_{1,28} = 1.29$, $p = 0.26$	–	$F_{1,28} = 0.76$, $p = 0.38$	–
double support time	**AP**	$F_{1,28} = 7.18$, **$p < 0.01$** ***PD > CG***	$F_{1,28} = 10.57$, **$p < 0.003$** ***DT < OC***	–	$F_{1,28} = 15.61$, **$p < 0.001$** ***DT < OC:CG(p < 0.001)/ PD > CG:DT(p < 0.002)***	–
	CP	$F_{1,28} = 6.01$, **$p < 0.02$** ***PD > CG***	$F_{1,28} = 2.54$, $p = 0.12$	–	$F_{1,28} = 14.13$, **$p < 0.001$** ***DT < OC:CG(p < 0.001)/ PD > CG:DT(p < 0.003)***	–

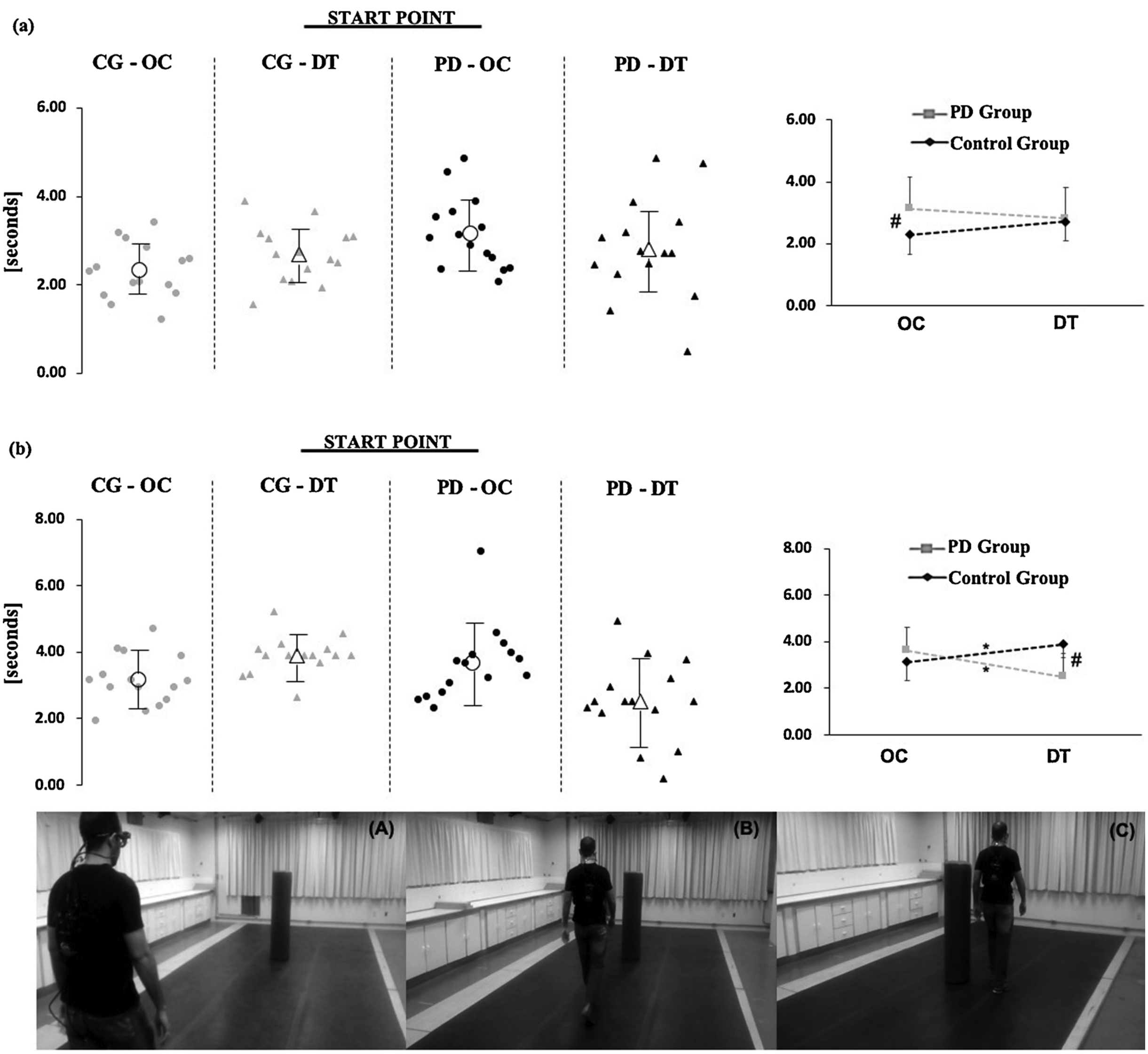

Fig. 2. Means of the moment of fixation on ground (a) and obstacle (b) areas according to condition – OC: obstacle circumvent without DT (circles), and DT: -obstacle circumvent with DT (triangle) – for each participant of the PD group (black symbols) and control group (gray symbols). The larger symbols represent mean, and the error bar indicates the standard deviation. Hashtag (#) indicates significant difference between groups; asterisk (*) indicates significant difference between conditions. In addition, the photos represent the participant performing the obstacle circumvention during walking in different phases of the task: (A) starting the trial, (B) approaching phase, (C) circumvention phase.

3. Results

There was no significant difference in Mini-Mental State Examination, DT performance and DT cost between the PD group and control group (Table 1). There were no obstacle contacts.

3.1. Gaze behavior

There were no main effects for group (Table 2, Figs. 1 and 2). The individuals, independent of group and condition (main effect of area), presented a higher number of fixations and longer time of fixations on the ground area than on the obstacle area. In addition, OCDT presented a longer mean duration of the fixations and reduced number of fixations compared to OC.

Group x condition interactions were identified for moment of fixation on ground and obstacle areas (Table 2 and Fig. 2). For ground fixations, the PD group fixated the ground earlier during the approach than the control group for OC, but the groups were not different for OCDT. Conversely, for obstacle fixations, the time of obstacle fixation was not different for OC, and the PD group delayed the obstacle fixation relative to the control group for OCDT.

Condition x area of interest interactions were identified for the mean duration of fixations. The participants performed longer mean duration of fixations on the ground area during OCDT compared to OC.

3.2. Spatial-temporal parameters

The PD group presented greater medial-lateral body clearance than the control group, but without a difference for horizontal body clearance (Table 2 and Fig. 3). OCDT increased the medial-lateral and horizontal body clearance compared to OC.

Group x condition interactions were identified for medial-lateral body clearance. The PD group presented greater medial-lateral body clearance during OCDT compared to OC. In addition, only when the obstacle circumvention was performed with DT, the PD group presented greater medial-lateral body clearance than the control group.

The spatial-temporal stride parameters for approaching phase and circumvention phase are presented in Table 3. The PD group walked

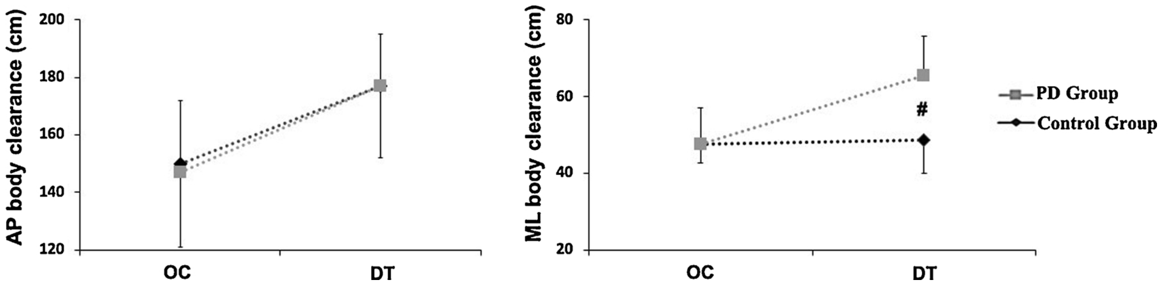

Fig. 3. A) Means and standard deviations of the anterior-posterior (AP) body clearance during walking with obstacle circumvention according to DT condition (without – OC - and with DT) in the PD group and control group. B) Means and standard deviations of the medial-lateral (ML) body clearance during walking with obstacle circumvention according to DT condition (without – OC - and with DT) in the PD group and control group. #: indicates difference between groups.

slower, with shorter stride length and longer double support time compared to the control group in both approaching and circumvention phases. During approaching phase, OCDT increased stride length and decreased double support time in both PD and control group.

Group x condition interactions were identified for double support time in both walking phases. The PD group presented longer double support time compared to the control group in OCDT for approaching and circumvention phases. In addition, the control group presented shorter double support time during DT in both phases.

4. Discussion

The novel finding of this study is that completing a cognitive task during obstacle circumvention delayed gaze fixation on the obstacle in people with PD, which could impair obstacle circumvention. In addition, cognitive task during obstacle circumvention evoked a compensatory motor behavior, increasing the safety (greater medial-lateral body clearance) and stability (longer double support time). On the other hand, neurologically healthy individuals performed gaze fixations on the obstacle earlier, which could improve the obstacle circumvention. In addition, interestingly, the PD group was able to concurrently perform both tasks, obstacle circumvention during walking and cognitive task. They had no obstacle contacts and similar DT performance and cost compared to control group. Besides, both groups increased stride length on approaching phase during DT, which was contradictory with previous literature that indicated DT increased cost in people with PD [13].

Delayed fixation on the obstacle is a result of DT during obstacle circumvention due to the increased cognitive load during the task. Gaze fixations on the obstacle provide not only visual feedback about target properties but fixations also have the potential to provide non-visual feedback, such as eye muscle proprioception and efference copy of eye movement commands [21]. In addition, gaze fixations represent the optimal acquisition period of the optical flow information, which is important to guide adjustments "en route" during walking [22]. As DT imposes an overload in the processing capacity in people with PD, the acquisition of optimal visual feedback was delayed, which could require a safely strategy to circumvent the obstacle (greater medial-lateral body clearance). However, we can argue that motor and gaze behavior were a result of DT. An explanation for this gaze delay in people with PD is that the supplementary motor area is activated prior to movement onset to provide the time necessary for the detailed processing of information and cortical organization of the neural structures underlying the planning and control of the action for effective motor performance [23]. The supplementary motor area is a pivotal area in the basal ganglia-cortical motor loop responsible to perform the communication between brain areas and to plan locomotion, which is impaired in PD [24]. In addition, gaze fixation requires an anticipatory attention on the object to prepare movement [22]. Distorted signals from visual feedback overload cognitive processing and attention in individuals with PD [25], which already is impaired in this population. Thus, DT attenuates visual performance when competition for cognitive control increases in people with PD [7]. Due to the effects of PD degeneration on the putamen area, which is responsible to the automatic movements [26], the cortical areas are activated increasing the processing workload and attentional competition [27], reducing the performance of visual feedback during walking. Therefore, the performance of obstacle circumvention during walking and cognitive task overloaded the cognitive capacity, requiring gaze and motor adjustments to be successful during the task.

People with PD were able to perform both tasks successfully. Our findings presented no obstacle contact and similar DT performance and cost between groups. In addition, DT increased step length for both neurologically healthy individuals and people with PD. This is an

Table 3
Means and standard deviations of the stride spatial-temporal parameters for approaching and circumvention phases on obstacle circumvention without (OC) and with DT (DT) in the PD group and control group. Hashtag (#) indicates group main effect; asterisk (*) indicates condition main effect; dagger (†) indicates interaction of group by condition.

	Control group		PD group	
	OC	DT	OC	DT
Approaching phase				
Stride length (cm)#*	106.8 ± 12.9	113.3 ± 11.4	91.1 ± 14.2	99.8 ± 17.4
Stride width (cm)	17.0 ± 6.4	21.4 ± 7.6	20.2 ± 3.5	20.1 ± 7.1
Stride duration (s)	1.07 ± 0.10	1.09 ± 0.12	1.07 ± 0.11	1.09 ± 0.17
Stride velocity (cm/s)#	101.4 ± 21.1	105.1 ± 16.3	85.5 ± 13.9	93.1 ± 20.1
Double support time (%)#*†	40.2 ± 2.6	25.1 ± 9.6	38.4 ± 5.0	39.9 ± 13.4
Circumvention phase				
Stride length (cm)#	109.1 ± 10.7	110.5 ± 13.9	90.3 ± 15.5	93.4 ± 16.1
Stride width (cm)	18.6 ± 6.6	20.0 ± 8.1	17.8 ± 3.8	17.1 ± 5.8
Stride duration (s)	1.10 ± 0.10	1.10 ± 0.15	1.07 ± 0.10	1.03 ± 0.17
Stride velocity (cm/s)#	100.1 ± 14.9	101.3 ± 15.2	84.3 ± 14.3	93.1 ± 21.1
Double support time (%)#†	40.3 ± 3.5	26.7 ± 8.5	38.2 ± 6.8	43.7 ± 18.3

interesting finding, but difficult to explain. The literature has consistently demonstrated negative effects of DT in people with PD in both gait and cognitive tasks [7,16,27], which are contrary to our findings. In addition, we argued in our previous study that obstacle circumvention is a challenging task for both neurologically healthy individuals and people with PD, which was used to explain the similar motor behavior between groups during obstacle circumvention without DT [3]. However, this explanation does not seem correct since both groups increased step length and had no obstacle contact or increased DT cost during obstacle circumvention with DT. Therefore, a possible explanation is that the DT used in our study did not require full cognitive reserve [28], which enabled the performance of both tasks at the same time. It is possible that the participants switch their attention momentarily to get the obstacle and get back to the cognitive task. An increased in the difficulty of cognitive task could cause a different motor behavior during obstacle circumvention. In addition, an increase in stride length suggests a functional adaptation of the locomotor synergy to deal with DT disturbance on gait [29] and to improve gait stability in this task [30].

The problems in making gaze fixations during DT in people with PD may be causally linked to impaired motor adjustments during walking and raise the possibility that interventions aimed at improving gaze behavior and perception may have a positive effect on locomotion. One possibility is training people with PD when and how to fixate the obstacle during walking. Therefore, it is recommended to include perception (visual) activities in motor training for people with PD.

5. Conclusion

In conclusion, obstacle circumvention with DT delayed gaze fixation on the obstacle in people with PD. In addition, they increased the safety and stability during the task as a result of DT. Finally, both neurologically healthy individuals and people with PD were successful during obstacle circumvention with DT. The results of this study suggest that deficits in locomotion during DT in people with PD may be caused, at least in part, by a reduced ability to fixate gaze at appropriate times during walking.

We also declare that research involving human subjects was performed in compliance with the principles of the Declaration of Helsinki (1964), and that was approved by the applicable institutional ethics committee (#45435615.7.1001.5398). We further attest that we have herein disclosed any and all financial and other relationships that could be construed as conflicts of interest, and that all sources of financial support for this study are disclosed in the manuscript.

Declaration of Competing Interest

We also declare that research involving human subjects was performed in compliance with the principles of the Declaration of Helsinki (1964), and that was approved by the applicable institutional ethics committee (#45435615.7.1001.5398). We further attest that we have herein disclosed any and all financial and other relationships that could be construed as conflicts of interest, and that all sources of financial support for this study are disclosed in the manuscript.

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