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Gaze and motor behavior of people with PD during obstacle circumvention

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ABSTRACT

The aim of this study was to analyze the motor and visual strategies used when walking around (circumvention) an obstacle in patients with Parkinson's disease (PD), in addition to the effects of dopaminergic medication on these strategies. To answer the study question, people with PD (15) and neurologically healthy individuals (15 – CG) performed the task of obstacle circumvention during walking (5 trials of unobstructed walking and obstacle circumvention). The following parameters were analyzed: body clearance (longer mediolateral distance during obstacle circumvention of the center of mass -CoM- to the obstacle), horizontal distance (distance of the CoM at the beginning of obstacle circumvention to the obstacle), circumvention strategy ("lead-out" or "lead-in" strategy), spatial-temporal of each step, and number of fixations, the mean duration of the fixations and time of fixations according to areas of interest. In addition, the variability of each parameter was calculated. The results indicated that people with PD and the CG presented similar obstacle circumvention strategies (no differences between groups for body clearance, horizontal distance to obstacle, or obstacle circumvention strategy), but the groups used different adjustments to perform these strategies (people with PD performed adjustments during both the approach and circumvention steps and presented greater visual dependence on the obstacle; the CG adjusted only the final step before obstacle circumvention). Moreover, without dopaminergic medication, people with PD reduced body clearance and increased the use of a "lead-out" strategy, variability in spatial-temporal parameters, and dependency on obstacle information, increasing the risk of contact with the obstacle during circumvention.

1. Introduction

Walking around obstacles and pedestrians, such as when individuals are moving around in malls or streets, is common during walking. Due to motor impairment and instability during walking, obstacle circumvention (OC) during walking is considered a major cause of falls [1]. OC affects walking even in young people, in that they reduce walking speed and step length during OC when compared to unobstructed walking [1]. One possible explanation for these reductions is the greater information processing demand that occurs when there is an obstacle in the environment [2]. Furthermore, adjustments in walking characteristics are more visible in older adults, who tend to avoid an obstacle by a greater distance from the obstacle [1] and reduce walking speed compared to younger adults during OC whilst walking [1]. This is due to increased motor deficits and impairments in selecting and processing environment information arising from the aging process [3]. These motor and sensory deficits may be exacerbated in people with PD [3,4], which could impair performance during OC.

People with PD present difficulty in dealing with challenging terrain, such as in the presence of an obstacle, which seems to be related to deficits in gait, vision and perception integration [5,6]. In addition, people with PD are more dependent on visual information during walking [7]. The control of gaze behavior presents implications for OC since eye movements are important for the quality of information sampled from the environment [8–11]. Dopaminergic medication (DOPA) appears to be effective for motor deficits, but not for sensory impairments in obstacle avoidance [8].

The aim of this study was to analyze the motor and visual behavior

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during OC whilst walking in patients with PD, in addition to the effects of DOPA. We hypothesized that people with PD would be more cautious compared to the control group during OC. In addition, people with PD would require more visual information from the environment, mainly from the obstacle, to perform OC. Due to motor impairments and deficits in associative cerebral pathways caused by lack of DOPA [12], we expected that people with PD OFF-medication would adopt risky behavior.

2. Method

The study included 30 individuals, 15 patients with PD (PDG, 5 men) and 15 neurologically healthy individuals (CG). An experienced neurologist evaluated and diagnosed patients with PD [13]. The groups were matched for demographic parameters.

The following exclusion criteria were considered for the sample composition: aged below 50 years, Hoehn & Yahr scale above stage 3 (H & Y) [14], cognitive decline, history of orthopedic problems, and vision incompatible with the experimental protocol. Moreover, as an inclusion criterion, the individuals with PD were required to be currently receiving medication treatment with levodopa.

After providing consent (CAAE:45435615.7.1001.5398), individuals were invited to participate in the evaluations described below. Clinical evaluations and OC were performed first in the PDG, in the OFF-state of medication (at least 12 h since the last dose of levodopa) and then in the ON-state of medication of PD (approximately one hour after taking the DOPA) [15]. If the patient was under treatment with a dopaminergic agonist, he/she was asked to remain without this medication for 24 h.

To determine the degree and stage of disease, patients were evaluated using the Unified Parkinson's Disease Rating Scale − UPDRS III [16], and the H & Y score, respectively. In addition, both groups performed the Mini-Mental State Examination [17] for cognitive function screening.

Participants walked at their own self-selected speed for a distance of 8.5 m on a walkway, 3.5 m wide. Participants performed five trials of unobstructed walking and five trials of OC. The order of trials was randomly determined. During obstacle trials, a cylinder foam obstacle with a diameter of 0.35 m and height of 1.30 m was positioned in the middle of the walkway and in the center, allowing a passage of 1.6 m each side. In addition, participants were instructed to walk around the obstacle and return to the same line where they were before OC. Participants self-selected the side to OC.

The tridimensional data was acquired by 8 cameras (Bonita System Cameras®)- 100 samples/s. For the unobstructed walking, the three central steps were considered for analyses. For the OC, five steps were analyzed: three steps before OC (N-3, N-2 and N-1) and two step during OC (N and N + 1).

Passive reflective markers were placed on participants' skin according to the Plug-in-Gait Full Body model (Vicon®) and four markers were placed on the obstacle. 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 tridimensional center of mass (CoM) coordinates based on the tridimensional coordinates of the 39 markers, which defined a 15-segment model [18]. Following the CoM coordinates, we calculated the body clearance [1,19] and horizontal distance at which participants started to circumvent the obstacle (defined as five standard deviations of a line drawn between the point the participant began the trial and the obstacle). In addition, the following spatial-temporal parameters of gait for each step were calculated: step length, width, duration and speed, and double support time (percentage of step duration). The strategy chosen by the participants to OC, “lead-out” (the lead limb is the farthest from the obstacle during crossing) or “lead-in”(lead limb is closest to the obstacle during crossing) strategy [19], was also determined.

Gaze behavior was recorded by a mobile eye-tracker (Mobile Eye-5 glasses®)- 60 samples/s. The eye tracker system was calibrated using the nine-point calibration method. Gaze fixation was considered when two times the point of gaze standard deviation was less than one degree of visual angle over at least 99 ms [7]. The following parameters were analyzed: total number of fixations, mean duration of the fixations, and time of fixations (percentage of travel time). In addition, gaze fixations were classified into four areas of interest: ground (any location on the ground before, after, or to the side of the obstacle), obstacle (any location on the obstacle), wall (any area on the wall at the end or on the side of the walkway), and random (any areas not included in the other three areas). Finally, we determined the percentage of trials that had no area of interest in the obstacle. The variability of each parameter was calculated from the coefficient of variation [13,20].

The significance level was maintained at 0.05. For clinical parameters, paired sample and independent sample Student *t*-tests were employed to compare DOPA effects (OFF x ON state) and cognitive status of the CG and people with PD in ON-state, respectively. The spatial-temporal parameters, body clearance, and horizontal distance, as well as the variability of these parameters, were compared by two-way ANOVAs, with factor group (PDG ON-state x CG) and step (unobstructed walking x N-3 x N-2 x N-1 x N x N + 1), with repeated measures for the last factor. Gaze behavior, as well as the variability of these parameters, were compared by two-way ANOVAs, with a factor of group and condition (unobstructed walking x OC), with repeated measures for the last factor. For areas of interest, the data were analyzed by two-way ANOVAs, with a factor for group and area of interest (ground x obstacle x wall x random), with repeated measures for the last factor. A separate analysis for people with PD was conducted with dopaminergic status in a within-subject design with ON and OFF DOPA state being a repeated-measure. In addition, Tukey post hoc tests were carried out to identify the significant differences when a significant main effect was found.

3. Results

3.1. Clinical variables

Patients with PD presented higher values of UPDRS-motor during the OFF-state. For other clinical parameters, there were no differences (Table 1).

3.2. CG X PDG

3.2.1. Body clearance, horizontal distance to obstacle, and obstacle circumvention strategy

There were no differences between the PDG and CG for body

Table 1
Clinical and anthropometric characteristics of all groups. *Difference between groups (t_{14} = 5.75; p < 0.001). MMSE: Mini Mental Status Exam. ON − under effects of dopaminergic medication. OFF − without effects of dopaminergic medication.

	Age (years)	Body Mass (kg)	Height (cm)	UPDRS-III (pts)	MMSE (pts)	H & Y
CG	65.33 ± 9.89	69.46 ± 15.74	1.59 ± 0.08	–	27.26 ± 1.48	
PDG	68.53 ± 5.84	69.13 ± 10.11	1.60 ± 0.06	24.73 ± 11.84 (ON)* 30.73 ± 9.77 (OFF)*	28.00 ± 2.53 (ON) 27.53 ± 2.64(OFF)	1.97 ± 0.67 (ON) 2.10 ± 0.54 (OFF)

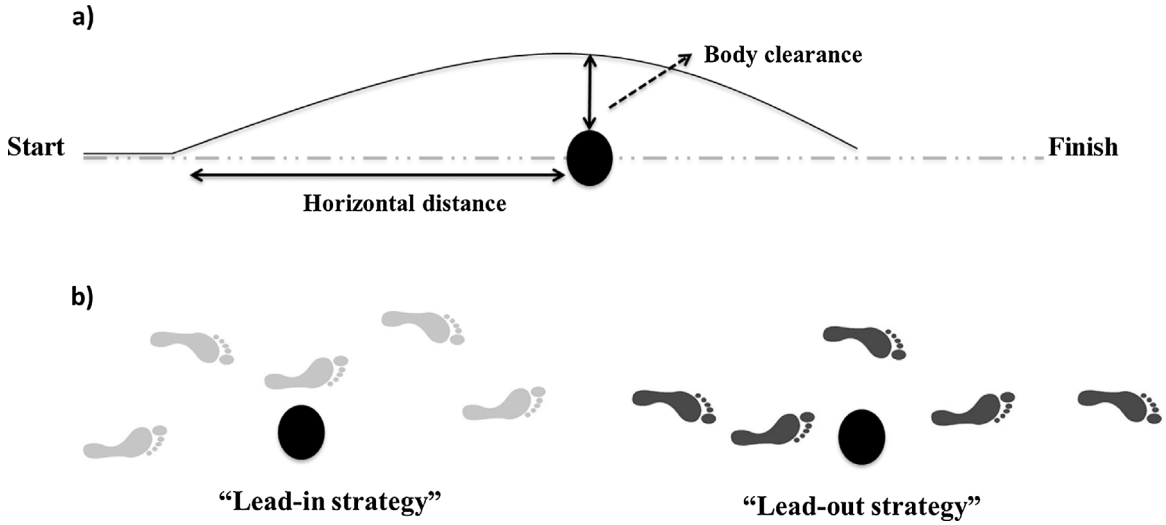


Fig. 1. Illustration of horizontal distance to the obstacle (beginning of circumvention). The black curve line represents the center of mass while the gray line the direction of walking (a). The two types of strategies of obstacle circumvention are below (b).

Table 2
Means and standard deviations of spatial-temporal parameters and variability (%) of these parameters (in the parenthesis) for the control group and people with PD (ON and OFF state of dopaminergic medication) during unobstructed walking (U.walk.) and steps of OC.

	CG		PDG OFF-state		PDG ON-state		Main effects ($F_{(1,28)}$ and *p*-values)		
Step length	**Mean (cm)**	**Variability (%)**	**Mean (cm)**	**Variability (%)**	**Mean (cm)**	**Variability (%)**	**Group**	**Step**	**Medication**
U.Walk.	63.01 ± 8.58	5.40 ± 2.09	49.60 ± 7.64	7.42 ± 3.71	53.10 ± 7.09	6.88 ± 3.42	**Mean**		
N-3	56.59 ± 8.71	8.57 ± 4.93	42.54 ± 8.22	15.41 ± 8.21	47.89 ± 7.85	9.61 ± 6.74	**F = 13.63**	**F = 18.68**	ns
N-2	54.28 ± 6.35	9.66 ± 4.43	43.50 ± 7.38	9.17 ± 3.80	44.94 ± 7.37	12.09 ± 6.24	**p < 0.001**	**p < 0.001**	
N-1	52.55 ± 7.27	11.17 ± 6.75	42.36 ± 9.04	13.85 ± 7.94	46.25 ± 7.46	11.21 ± 4.81	**Variability**		
N	55.34 ± 5.16	8.94 ± 4.95	42.62 ± 8.77	13.45 ± 11.11	45.40 ± 8.55	13.86 ± 6.71	**F = 5.71**	**F = 5.74**	ns
N + 1	53.76 ± 7.07	8.97 ± 4.08	42.39 ± 8.78	18.01 ± 8.51	44.94 ± 9.35	15.69 ± 9.17	**p < 0.02**	**p < 0.001**	
Step width	**Mean (cm)**	**Variability (%)**	**Mean (cm)**	**Variability (%)**	**Mean (cm)**	**Variability (%)**			
U.Walk.	14.74 ± 4.56	26.25 ± 10.72	15.15 ± 4.99	35.86 ± 19.71	15.17 ± 5.27	30.28 ± 16.42	**Mean**		
N-3	15.24 ± 3.94	30.14 ± 14.69	17.12 ± 4.24	35.86 ± 19.74	16.67 ± 4.14	30.28 ± 16.46	ns	ns	ns
N-2	17.41 ± 7.15	32.16 ± 21.02	22.09 ± 6.75	36.64 ± 26.87	21.24 ± 5.78	41.16 ± 22.64			
N-1	16.70 ± 6.84	51.40 ± 34.92	17.71 ± 6.15	56.7 ± 29.78	19.16 ± 5.76	50.22 ± 24.23	**Mean**		
N	19.86 ± 10.95	31.91 ± 15.56	19.44 ± 6.55	42.08 ± 18.31	19.07 ± 5.66	39.61 ± 15.51	ns	ns	ns
N + 1	17.35 ± 7.85	41.82 ± 21.54	17.93 ± 5.14	42.45 ± 23.32	16.61 ± 6.23	44.11 ± 22.14			
Step duration	**Mean (s)**	**Variability (%)**	**Mean (s)**	**Variability (%)**	**Mean (s)**	**Variability (%)**			
U.Walk.	0.53 ± 0.05	4.18 ± 2.23	0.54 ± 0.06	5.51 ± 2.91	0.52 ± 0.52	5.37 ± 2.68	**Mean**		
N-3	0.53 ± 0.01	4.57 ± 2.53	0.54 ± 0.06	6.74 ± 4.89	0.53 ± 0.04	5.88 ± 3.54	**ns**	**ns**	ns
N-2	0.52 ± 0.05	4.72 ± 2.18	0.54 ± 0.06	6.79 ± 2.94	0.53 ± 0.05	5.65 ± 2.13			
N-1	0.54 ± 0.05	5.04 ± 3.17	0.54 ± 0.07	6.51 ± 4.23	0.53 ± 0.06	7.64 ± 3.77	**Variability**		
N	0.55 ± 0.05	5.22 ± 3.20	0.55 ± 0.05	8.28 ± 3.24	0.54 ± 0.05	7.60 ± 3.82	**F = 6.03**	**ns**	ns
N + 1	0.54 ± 0.05	6.31 ± 4.31	0.54 ± 0.06	7.24 ± 3.76	0.53 ± 0.05	8.80 ± 6.44	**p < 0.02**	**ns**	ns
Step velocity	**Mean (cm/s)**	**Variability (%)**	**Mean (cm/s)**	**Variability (%)**	**Mean (cm/s)**	**Variability (%)**			
U.Walk.	120.77 ± 24.55	5.21 ± 2.57	93.88 ± 20.05	8.72 ± 4.42	102.33 ± 17.48	7.77 ± 3.70	**Mean**		
N-3	107.68 ± 22.5	8.03 ± 3.86	79.95 ± 18.54	14.76 ± 8.14	89.35 ± 15.35	10.38 ± 5.53	**F = 7.52**	**F=26.27**	ns
N-2	104.26 ± 20.1	8.00 ± 4.59	79.9 ± 14.04	10.89 ± 5.33	84.93 ± 14.72	13.64 ± 6.90	**p < 0.01**	**p < 0.001**	
N-1	98.49 ± 22.5	10.83 ± 6.92	78.33 ± 17.82	16.48 ± 9.81	86.71 ± 13.71	10.51 ± 5.00	**Variability**		
N	101.30 ± 13.8	8.85 ± 4.53	77.64 ± 16.41	14.45 ± 11.83	84.80 ± 16.22	15.09 ± 6.83	**F = 8.32**	**F = 6.10**	**F = 2.49**
N + 1	99.51 ± 17.42	9.74 ± 5.60	77.79 ± 16.12	18.79 ± 9.25	84.01 ± 14.93	14.58 ± 7.85	**p < 0.007**	**p < 0.001**	**p < 0.05**
Double support	**Mean (%)**	**Variability (%)**	**Mean (%)**	**Variability (%)**	**Mean (%)**	**Variability (%)**			
U.Walk.	38.84 ± 2.54	7.07 ± 5.66	36.94 ± 6.31	12.17 ± 8.18	35.02 ± 7.06	11.17 ± 6.17	**Mean**		
N-3	38.96 ± 3.32	9.79 ± 7.19	39.97 ± 6.35	11.03 ± 8.28	38.24 ± 5.74	13.81 ± 11.44	**ns**	**F = 2.68**	ns
N-2	39.70 ± 2.52	8.12 ± 5.50	39.71 ± 6.34	10.74 ± 7.73	38.95 ± 4.43	14.44 ± 9.74		**p < 0.05**	
N-1	40.76 ± 3.27	8.81 ± 5.08	38.46 ± 5.68	10.59 ± 7.24	37.95 ± 5.89	15.63 ± 10.21	**Variability**		
N	39.62 ± 3.38	9.93 ± 5.71	39.19 ± 5.69	15.64 ± 10.00	38.05 ± 7.28	15.85 ± 9.69	**F = 7.95**	ns	ns
N + 1	41.11 ± 4.75	11.79 ± 6.55	38.29 ± 6.87	15.55 ± 10.33	38.43 ± 7.97	23.50 ± 13.83	**p < 0.009**		

clearance, horizontal distance to obstacle (Fig. 1), or variability of these parameters. "Lead-in" and "lead-out" strategies were used in 56% and 44% of the CG, respectively, and 52% and 48% of the PDG, respectively. In addition, PDG and CG circumvented the obstacle to the least affected side in 54.70% of trials and to dominant side in 61.30% of trials, respectively.

3.2.2. *Spatial-temporal parameters*

The PDG decreased step length and velocity compared to the CG (Table 2). Both the PDG and CG decreased step length and velocity for all steps during OC compared to unobstructed walking ($p < 0.05$). In addition, the furthest step from the obstacle (N-3) presented a longer step length than steps N-2 ($p < 0.04$) and N-1 ($p < 0.02$) and a

Table 3
Means and standard deviations of gaze parameters and variability for the control group and PD group in ON and OFF states of dopaminergic medication during unobstructed walking and obstacle circumvention.

	CG		PDG OFF-state		PDG ON-state		Main effects ($F_{(1,28)}$ and p-values)		
	Unobstructed walking	Obstacle circumvention	Unobstructed walking	Obstacle circumvention	Unobstructed walking	Obstacle circumvention	Group	Step	Medication
Number of fixations (n)	8.89 ± 4.10	8.43 ± 3.57	11.52 ± 8.52	11.98 ± 8.09	10.34 ± 6.88	10.26 ± 6.98	ns	ns	ns
Mean duration of fixations (s)	0.15 ± 0.01	0.15 ± 0.01	0.17 ± 0.04	0.24 ± 0.17	0.18 ± 0.09	0.19 ± 0.08	ns	ns	**F = 4.01 p < 0.05**
Time of fixations (%)	29.11 ± 13.39	28.54 ± 13	30.46 ± 19.27	31.30 ± 17.89	33.44 ± 15.53	28.8 ± 15.08	ns	**F = 4.48 p < 0.04**	**F = 4.37 p < 0.05**
				VARIABILITY					
Number of fixations (%)	31.30 ± 17.01	30.35 ± 19.70	39.76 ± 56.41	43.62 ± 51.09	30.55 ± 14.48	30.55 ± 17.54	ns	ns	ns
Mean duration of fixations (%)	18.51 ± 7.34	17.09 ± 5.95	21.29 ± 19.74	21.42 ± 13.03	20.33 ± 11.76	21.16 ± 11.02	ns	ns	ns
Time of fixations (%)	1.87 ± 1.80	2.21 ± 2.12	5.67 ± 8.88	8.47 ± 12.56	2.84 ± 3.08	4.72 ± 4.81	ns	ns	ns

higher step velocity than step N-1 ($p < 0.01$). Furthermore, steps N-2 ($p < 0.04$) and N-1 ($p < 0.02$) presented longer double support duration compared to unobstructed walking.

For variability, the PDG presented greater variability in step length, duration and velocity, and double support duration than the CG. Steps N-2 ($p < 0.003$; $p < 0.01$), N-1 ($p < 0.002$; $p < 0.05$), N ($p < 0.001$; $p < 0.001$), and N + 1 ($p < 0.003$; $p < 0.005$) of OC demonstrated greater variability in step length and velocity compared to unobstructed walking. In addition, unobstructed walking presented less variability in step width ($F_{1,28} = 7.97$,$p < 0.001$) than steps N-1 ($p < 0.001$), N ($p < 0.02$), and N + 1 ($p < 0.001$) of OC. Moreover, step N-1 presented greater variability in step width than step N-3 ($p < 0.001$) during the OC task.

For group*step interaction, the PDG presented greater variability in step length ($F_{1,28} = 4.12$, $p < 0.05$) compared to the CG for steps N ($p < 0.001$) and N + 1 ($p < 0.001$) and greater variability in step velocity ($F_{1,28} = 5.78$, $p < 0.05$) and double support duration ($F_{1,28} = 4.78$, $p < 0.03$) than the CG for unobstructed walking ($p < 0.03$; $p < 0.05$), and N-2 ($p < 0.01$; $p < 0.03$), N ($p < 0.006$;$p < 0.05$), and N + 1 ($p < 0.05$; $p < 0.006$) during OC. Specifically for the CG, the variability of step length was greater in OC for steps N-2 ($p < 0.01$), N-1($p < 0.001$), and N ($p < 0.01$) compared to unobstructed walking. For step width ($F_{1,28} = 7.97$, $p < 0.04$), unobstructed walking ($p < 0.003$), N-3 ($p < 0.01$), N-2 ($p < 0.01$), and N ($p < 0.02$) presented lesser variability than step N-1. Specifically for the PDG, steps N-2 ($p < 0.003$, $p < 0.001$), N-1 ($p < 0.01$; $p < 0.05$), N ($p < 0.001$; $p < 0.001$), and N + 1 ($p < 0.001$; $p < 0.002$) presented greater variability in step length and velocity than unobstructed walking. In addition, steps N-2 ($p < 0.01$, $p < 0.05$) and N-1 ($p < 0.007$, $p < 0.03$) presented lesser variability in step velocity than steps N and N + 1. Finally, all steps in OC presented greater variability in step width than unobstructed walking ($p < 0.05$).

3.2.3. Gaze behavior

Without considering areas of interest (Table 3), both the PDG and CG presented higher time of fixation during unobstructed walking compared to walking with OC. There were no effects for other variables or variability of gaze parameters.

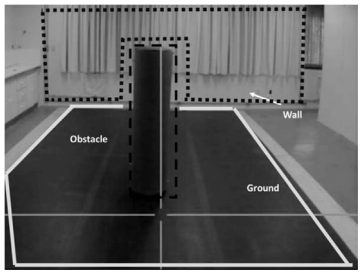
For areas of interest (Table 4), there were a higher number ($F_{3,84} = 50.17$, $p < 0.001$), mean duration ($F_{3,84} = 5.29$, $p < 0.01$), and time of fixations ($F_{3,84} = 48.80$, $p < 0.001$) on the ground than other areas of interest ($p < 0.001$). In addition, there was a higher number, mean duration, and time of fixations on the obstacle than the wall ($p < 0.001$) or random ($p < 0.001$). For the group*areas of interest interaction, the PDG decreased mean duration of fixations ($F_{3,84} = 3.92$,$p < 0.03$) on the wall compared to the CG ($p < 0.04$). Specifically for the CG, mean duration of fixations on the ground was higher than random ($p < 0.03$), while for the PDG, mean duration of fixations on the ground and on the obstacle was higher compared to the wall ($p < 0.004$; $p < 0.003$) and random ($p < 0.007$; $p < 0.05$). In addition, CG and PDG did not fixate the obstacle in 46.66% and 36.00% of trials, respectively.

3.3. Effects from dopaminergic medication

DOPA increased body clearance ($F_{1,28} = 4.30$, $p < 0.04$), but without significant influences on horizontal distance to obstacle and variability of body clearance or horizontal distance to obstacle (Fig. 2). Without effects of DOPA, the PDG increased the use of the “lead-out” strategy (OFF:60%; ON:48%) and percentage to circumvent the obstacle to the least affected side (OFF:61.4%; ON:54.7%).

DOPA had no effects on spatial-temporal parameters, but when the PDG were in the OFF state, they increased variability in step velocity of step N-1 ($p < 0.04$) (Table 2). In addition, patients with PD in the ON-state presented a decreased time of fixations; while in the OFF-state, the

Table 4
Mean values and variability of gaze parameters for each area of interest. Figure illustrates each area, the crosshair illustrates where the participant was looking. Random was considered when the participant did not look at any of these areas.



Areas of interest	Number of fixations (n)			Mean duration of fixations (s)			Time of fixations (%)		
	CG	PDG OFF-state	PDG ON-state	CG	PDG OFF-state	PDG ON-state	CG	PDG OFF-state	PDG ON-state
Ground	6.04 ± 3.39	8.20 ± 7.58	6.99 ± 4.90	0.14 ± 0.05	0.16 ± 0.05	0.15 ± 0.04	20.25 ± 12.63	19.48 ± 15.08	18.74 ± 11.57
Obstacle	1.73 ± 1.85	2.25 ± 1.95	2.37 ± 2.15	0.13 ± 0.04	0.19 ± 0.05	0.15 ± 0.04	5.88 ± 6.28	6.84 ± 6.20	7.11 ± 6.08
Wall	0.63 ± 1.64	3.13 ± 8.14	0.16 ± 0.43	0.13 ± 0.18	0.07 ± 0.10	0.03 ± 0.06	1.39 ± 1.94	2.07 ± 4.57	0.54 ± 1.53
Random	1.23 ± 2.19	6.13 ± 10.91	0.76 ± 1.42	0.10 ± 0.09	0.09 ± 0.11	0.09 ± 0.07	0.96 ± 1.01	2.44 ± 3.44	1.46 ± 2.44

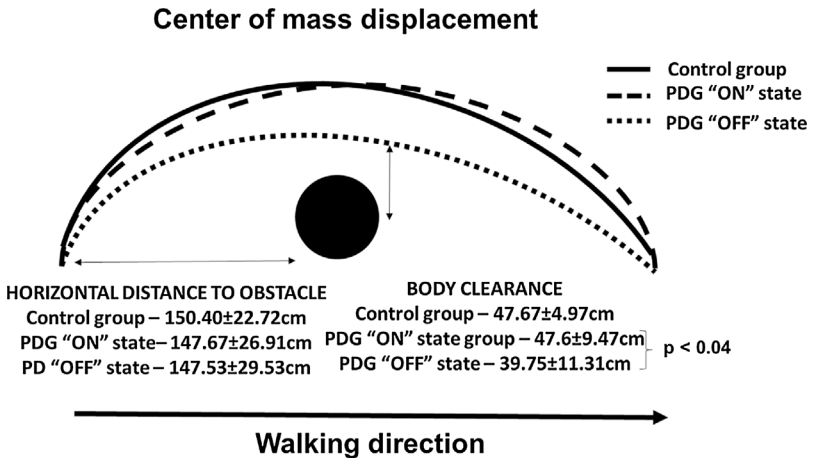


Fig. 2. Schematic representation of body clearance and horizontal distance to obstacle. The figure includes means and standard deviations of these parameters for the PD group under (ON) and without (OFF) effects from dopaminergic medication, and the control group.

PDG increased mean duration of fixations during OC compared to unobstructed walking (Table 3). There were no effects of variability of gaze behavior parameters.

For area of interest (Table 4), the PDG in the OFF-state presented longer mean duration of fixations ($F_{3,84} = 20.38, p < 0.001$) on the obstacle. In addition, in the ON-state, they presented longer mean duration of fixations on the ground and obstacle compared to other areas of interest ($p < 0.02$) while in the OFF-state, they presented longer mean duration of fixations on the ground compared to other areas of interest ($p < 0.01$). Finally, DOPA did not affect the percentage of trials that had no area of interest in the obstacle (OFF:34.3%; ON:36%).

4. Discussion

This is the first study to investigate OC during walking in people with PD. Our findings indicated that OC during walking was a more challenging task for both the PGG and CG. The main findings of our study were i) the PDG and CG presented similar OC behavior (no differences between groups for body clearance, horizontal distance to obstacle or OC strategy), but the groups used different adjustments to perform this behavior; ii) lack of DOPA increased the risk of contact with the obstacle during circumvention, the variability in the final step (N-1) before OC, and visual dependence on the obstacle.

4.1. OC during walking in people with PD

Impairment in the basal ganglia did not appear to affect the safety of PDG (in ON-state) during OC. They dealt with OC similarly to the CG. Two possible approaches to understanding the similarity between groups in the behavior of OC are i) OC during walking was a challenging task for both groups. OC requires that the individual detects the obstacle's position and edges, performs precise motor actions to move around it, and allows adequate space between the obstacle and the body at the point of moving past it to ensure safe navigation [21]. OC makes walking less automatic and more dependent on cortical control [22], causing a reduction in stability and increasing the risk of falling [11]. To deal with the challenge and instable task, both groups increased the duration of double support and reduced step length and velocity. Longer duration of double support in the last two steps before OC kept the individuals on a more stable basis of support. In addition, reduction in walking velocity and step length seems to be a strategy aimed at improving stability during complex locomotor tasks [23]. On the other hand, slower gait speed provides an additional time between steps to plan the circumvention strategy earlier, and execute adjustments, to conclude the locomotor task [15], which is important to compensate the reduction in time of fixations during OC found in the present study; ii) both groups sought safe behavior during OC. They started OC and used adequate body clearance to avoid touching the obstacle. The PDG and CG touched the obstacle in just two trials and one trial,

respectively. To seek safety during the task, both groups increased the number of fixations on the obstacle and ground, presumably to obtain visuospatial information, adapting the location of their footsteps and travel path before OC, and adjusting the obstacle distance for a safe maneuver [4]. However, although there were similar behaviors to OC, the groups used different adjustments to be efficient in the behavior.

The PDG adjusted the spatial-temporal parameters during all steps analyzed. On the other hand, the CG preferred to adjust these parameters near to OC (N-1). This is common behavior for OC, where adjustments for obstacle avoidance are made within one stride from an obstacle [1,19,24] through step width modulation for the mediolateral control of the CoM and step length modulation for gait speed reduction while walking rhythmicity is maintained [1,19]. However, the PDG adjusted their walk during the approach, by feedforward corrections, and circumvention, by online corrections, phases. The requirement to adjust the CoM trajectory from time-to-time during walking with OC increased variability of spatial-temporal parameters in the PDG, which may be interpreted as deficits in the internal rhythmicity [25], causing inconsistency in stepping patterns and balance impairments [17]. In addition, previous studies have demonstrated visual sampling impairment in PDG [26,27], which requires visual identification of obstacles. The greater dependency on visual obstacle information may be explained due to working memory and/or executive function deficits caused by the disease. PDG present difficulty remembering locations [28] and require eye movements to visual targets to take advantage of direct sensory-to-motor mapping in structures like the superior colliculus [29]. Declines in executive cognitive functioning require prolonged gaze fixation time on visual information [10] during challenging walking [30], in our case the obstacle, to compensate longer information processing duration.

4.2. Effects of dopaminergic medication on OC during walking

Withdrawal of DOPA increased the risk of contact with the obstacle during circumvention. Basal ganglia functioning seemed to be impaired without effects from DOPA in the PDG, who reduced body clearance, and increased the use of a “lead-out” strategy, variability of N-1 and N, and dependency on obstacle information. DOPA appears to have improved the communication between cerebral planning areas and basal ganglia [29]. Previous studies have indicated that DOPA is efficient to improve both motor and sensory systems [8]. Reducing body clearance does not provide an adequate distance or time to adjust walking for obstacle avoidance, which seems a direct effect of failure in environment perception. The increased “lead-out” strategy demonstrated an attempt to compensate the shorter body clearance. However, despite seeming an interesting strategy to place the foot far from the obstacle, when people with PD placed the other foot to circumvent the obstacle, they neared their CoM to the obstacle, which could be an inefficient strategy. In addition, the increased variability indicated an inconsistent adjustment to OC, which corroborates previous studies that analyzed gait variability in PDG in an OFF-state [8]. Finally, the greater dependency on obstacle information evidenced that DOPA could improve visual information selection in PDG, providing visual information to improve foot placement and travel path.

5. Conclusion

In conclusion, OC during walking was a challenging task for both the PDG and CG. Under the effects from DOPA, PDG presented similar OC behavior to the CG, but the manner in which they performed the adjustments was different. While the PDG performed adjustments during both the approach and circumvention steps and presented greater visual dependence on the obstacle, the CG adjusted only the final step before OC. However, without effects of DOPA, the PDG were not able to perform the same behavior as under the effects of DOPA, increasing the risk during OC.

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