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Medication status and dual-tasking on turning strategies in Parkinson disease

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ABSTRACT

Background: Parkinson disease (PD) patients have turning impairments that may increase fall risk. Clinics lack specialized kinematic equipment used in gait and turn analysis and require a simple method to evaluate fall risk and advise patients in turning strategy selection.

Objectives: To enhance understanding of PD turning strategies and determine if turning can be assessed using a video-recording and categorization method, we compared 180-degree and 90-degree turns as a function of medication status and dual-tasking (DT).

Methods: 21 PD participants (H&Y stage 1–3) in PD-ON and PD-OFF medication states and 16 controls completed 180-degree and 90-degree turn-tasks with and without DT. Video-recordings of tasks permitted classification of 180-degree turns into Few-Step turns (FST) vs. Multi-Step turns (MST) and 90-degree turns into Step vs. Spin-turns. FST were further sub-classified into Twisting vs. Sideways turns and MST into Backward, Festination, Forward or Wheeling turns. Percentages of subtypes were analyzed across groups by task.

Results: IN 180-degree tasks, there was an effect of group: FST vs. MST $F(2,55) = 9.578$, $p < .001$. PD participants in the off-medication state (PD-OFF) produced significantly more MST with a larger number of different turning subtypes vs. controls or PD on medication (PD-ON). In 90-degree tasks, controls significantly increased their proportion of Step-turns while DT ($p < .001$), an adaptation not observed in PD-ON or PD-OFF.

Conclusions: PD turning impairments may stem from an inability to select a unified turning strategy and to adapt to the turning environment, which may be exacerbated in PD-OFF. Video-analysis may prove beneficial in predicting a clinical course for PD patients by revealing features of turning dysfunction.

1. Introduction

Falling and fear of falling are common yet complex issues in Parkinson disease (PD) that substantially affect quality of life. Current reports suggest that incidence and fear of falling stem largely from turning hesitations rather than gait impairments [1,2]. In routine daily activities, an individual performs at least two turns for every ten steps taken [3]. However, the main body of literature examines straight walking in PD and has neglected to examine turning strategies in these individuals.

Categorization of turn styles has revealed that different turn stepping patterns are used by individuals with PD when compared to healthy controls [4,5]. Current methods of gait and turn analysis rely on specialized kinematic equipment, which is inaccessible in most clinical situations. Thus, objective gait and turn analysis is not utilized when making clinical decisions. Clinical observation and videotaping are easily available and can be employed in all clinics. Given that the selected turning strategies of individuals with PD contributes to fall risk, the ability to assess turn strategies during routine clinic visits would provide a better understanding of fall risk in individuals with PD. King et al., (2012) report that the current clinical evaluation of turning in PD is inadequate; they suggest that turning deficits are present in even mild PD, but are not obviously reflected in common clinical scales of balance, such as the Berg or Tinetti [6] Glaister and colleagues (2007)

Abbreviations: ABC, Activities Balance Confidence Scale; **ANOVA**, Analysis of Variance; **DT**, Dual Tasking; **FOG**, Freezing of Gait; **FST**, Few Step Turn; **H&Y**, Hoehn and Yahr Scale; **MST**, Multi-step Turn; **LED**, Levodopa Equivalence Dose; **MOCA**, Montreal Cognitive Assessment; **PD**, Parkinson Disease; **PD-ON**, Participant with PD who is currently ON their medication; **PD-OFF**, Participant with PD who is OFF medication, following 12-h withdrawal

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suggested the use of video analysis as a method for assessing turns during activities of daily living [7]. Therefore, a key goal of this study was to test the plausibility of simple video-based recording and visual analysis, with practical gait and turning tasks, in order to reveal features of turning dysfunction. If so, such tasks could be implemented in clinic to help physicians identify unsafe turn strategies used by PD patients and thus give insight regarding how to reduce fall risk.

Since many motor symptoms of PD respond well to changes in dopaminergic medications, it is reasonable to predict that turning patterns would differ as a function of medication status ('ON' vs. 'OFF'). Moreover, there is increasing evidence suggesting that the execution of gait tasks with an additional cognitive load can lead to marked deterioration in gait performance [8]. Such "dual-tasking" (DT) paradigms mimic typical multi-tasking activities and have been shown to be particularly difficult for individuals with PD [8,9]. If true, DT conditions may reveal disruptions in turning strategy that are not visibly apparent during single-task oriented turns. While well established in literature that both medication status and DT affect gait performance in PD [8–11], the effect of these variables on turning in PD remains relatively unexplored. Few published studies have investigated the effect of medication or DT on turning (i.e., using only 180-degree turns) reporting minimal differences as a function of medication status [12,13]. Given the importance of turning and its influence on fall risk in PD, further investigation of the impact of medication and DT on turning is warranted.

The primary objective of this study was to investigate the effect of 'ON' and 'OFF' medication states on turning strategy in 180-degree and 90-degree turning tasks. Within 90-degree turns, we additionally investigated the influence of motor and cognitive loads on turning patterns. The secondary objective was to explore the possibility of using video recording to assess turning strategies during the performance of each task. The goal is to demonstrate that simple video recording can detect turning differences in individuals with PD.

2. Materials and methods

This protocol was approved by the Health Sciences Research Ethics Board at Western University (HSREB # 6828) in accordance with the Declaration of Helsinki regarding research with human subjects. Written, informed consent was provided by all participants.

2.1. Participants

A convenience sample of twenty-one participants with idiopathic PD (Hoehn and Yahr (H&Y) Stage = 1–3; higher value indicates increasing disease severity to a maximum of 5) collected from the Movement Disorder Centre at London Health Sciences Centre and sixteen age-matched controls were recruited. Inclusion criteria for PD participants included: 1) stable levodopa management for at least twelve months, 2) no significant motor fluctuations (both 'ON' and 'OFF' states are predictable, responding well to levodopa), 3) no freezing of gait (FOG) symptoms based on clinical examination, subjective reporting by the patient and the motor component of the Unified Parkinson's Disease Rating Scale (UPDRS-III) [14]. Status of freezing was reported by the patient, which included both 'ON' and 'OFF' levodopa time periods. Patients were not included in the study if they routinely experienced FOG. Further, for both PD participants and controls, inclusion criteria specified no preceding history of neurological/ musculoskeletal procedures or conditions that would impair motor function. Participants completed a series of assessments to establish baseline motor and cognitive profiles (See Table 1 for full description and relevant statistical comparisons of clinical assessments). Clinical scales performed on PD participants were completed in the 'ON' medication state. The Activities and Balance Confidence Scale (ABC) was completed by the patient to assess confidence performing ambulatory activities without falling. The ABC has been shown to be a valid and reliable measure for fall risk in individuals living with PD [15]. Individuals additionally completed an in-house fall risk assessment, which outlined their fear of falling and number of falls in the last year that each participant sustained prior to the initiation of the study. The questions were as follows:

1. Do you think you are at a higher risk for falling? (Yes/No)
2. Do you limit any household activities because you are frightened you may fall? (Yes/No)
3. Do you limit any non-household activities because you are frightened you may fall? (Yes/No)
4. How many times have you fallen in the last month? (0 or > 0)
5. How many times have you fallen in the last year? (0 or > 0)
6. Have these falls resulted in any significant injuries (Requiring hospitalization)? (Yes/No)

Table 1
Description of demographic variables and relevant statistical comparisons for those with Parkinson Disease (PD) in "off" (PD-OFF) and "on" (PD-ON) medication states. Data presented as mean (M) ± standard deviation (SD); Levodopa Equivalence Dose (LED).

Characteristic	PD-OFF M ± SD	PD-ON M ± SD	Control M ± SD
Age (yrs)	–	69.81 ± 6.91	66.19 ± 7.87
Gender (% female)	–	29.17 ± 9.48%	56.25 ± 12.81%
Height (m)	–	1.72 ± 0.08	1.75 ± 0.10
Weight (kg)	–	77.78 ± 19.26	85.62 ± 17.12
Mean disease duration (yrs)	–	7.70 ± 4.33	–
LED (mg)	–	716.05 ± 412.02	–
Motor function *	25.905 ± 13.43	16.913 ± 11.99	–
(UPDRS III score)	$t(20) = 4.492$, $p < .01$, 95% CI [−12.55 to −4.591]		
Axial subscore	4.286 ± 2.87	3.047 ± 2.67	–
(Items 18, 29–31 from UPDRS III)	$t(20) =$, $p < .01$, 95% CI[0.60 to 1.88]		
Cognition	–	24.19 ± 4.06	26.20 ± 3.88
(Montreal Cognitive Assessment Score (MoCA))		$t(34) = 1.492$, $p = .145$, 95% CI [−0.73 to 4.75]	
Balance Confidence*	–	76.04 ± 0.22%	90.98 ± 0.12%
(Activities and Balance Confidence Scale (ABC))		$t(34) = 2.300$, $p < .05$, 95% CI [1.69 to 27.28]	
Time needed to perform test *	15.16 ± 4.93**	13.96 ± 4.28	11.70 ± 1.45**
(Time in seconds to walk 10 ft., turn 180° and return to start position)	$F(2,55) = 3.399$, $p < .05$, $\eta_p^2 = 0.11$		
Proportion of those who fell in the last year *	–	52.38%	18.75%
Proportion of those who limit activities due to fear of falling *	–	71.43%	6.25%

Note: MoCA and ABC data was not available for one control participant so they were omitted from these entries. * $p < .05$, **significant post-hoc result $p < .05$.

Table 2
Description of 180-degree and 90-degree turning tasks.

180-degree turns:		
Task #	**Components**	**Description**
Task 1	180-degree turn	Participants were instructed to walk forward 10 ft (3.05 m), turn 180-degrees at a marker and return to start position. Total of 6 trials. No cue was provided on which direction to turn.
90-degree turns:		
Task #	**Components**	**Description**
Task 2	90-degree + turn in a predicted direction	Prior to task initiation, participants were instructed to walk forward 10 ft (3.05 m), turn 90-degrees right or left at a marker, continue walking straight for 10 ft (3.05 m) until they reached a second marker, and then return to start position. Total of 6 trials; 3 left and 3 right
Task 3	90-degree + turn in an unpredicted direction	Identical to Task 2 except the direction of turn was not provided prior to initiation of walking. As participants approached the marker a verbal cue was provided to turn "left" or "right". Total of 6 trials; 3 left and 3 right
Task 4	90-degree + turn in an unpredicted direction + dual cognitive load	Identical to task 3 except participants simultaneously completed a secondary dual cognitive task requiring serial subtractions. Total of 6 trials; 3 left and 3 right with randomized serial subtractions (7's, 5's, 3's, 1's, 2's, 4's)

2.2. Turning tasks

PD participants completed the experimental protocol twice, first in an 'OFF' medication state, defined as a 12-h overnight withdrawal of levodopa (PD-OFF), and then again after administration of 125% of their regular levodopa dose (PD-ON) [16]. A minimum wait time of 45 min was used to allow the patients to be fully 'ON'. Controls completed the protocol only once.

All participants executed a series of four tasks: Task 1) planned 180-degree turns, Task 2) planned 90-degree turns, Task 3) unanticipated 90-degree turns and Task 4) unanticipated 90-degree turns with cognitive DT, requiring serial subtractions. The participants were asked to complete 6 trials within each turning task, for a total of 24 trials per participant. During tasks 3 and 4, the auditory cue for turn direction was given from the same position for every participant. During task 4, the participants were asked to perform serial subtractions. This task was randomized across the subtraction numbers by writing all the numbers into pieces of paper and drawing the number from a hat. The randomization was performed with replacement, meaning once a number was drawn it was returned to the hat and could be used again. All turns were dynamic such that participants walked straight for 10 ft (3.05 m) prior to entering the target turn. Participants were not instructed how to turn, or which foot to use first while turning. Tasks are described in full detail in Table 2. Each turn task, both 180-degree and 90-degree turns, took approximately 5–8 min to complete (rests were given between each trial).

Task performance were audio and video recorded using a digital video-recorder (Sony DCR-TVR330). The video camera was positioned outside of the turning zone, facing the participants to avoid interfering with tasks. Participants were then recorded walking toward the video camera, which was then panned left or right depending on the turn direction. Videos were independently edited to include only turn tasks themselves in an attempt to reduce cognitive bias from a "halo effect" [17]. Two trained researchers, blinded to participant subtype and medication state, analyzed the videos classifying turns for data analysis.

2.3. Turn classification

Definitions of turn subtypes used for classification were adapted from Stack and colleagues and are presented in Fig. 1 [18]. Turns for the 180-degree task were classified into Few-step turns (FSTs; ≤ 3 steps) or Multi-step turns (MSTs; > 3 steps) [18]. To further investigate specific turn strategies utilized by participants, FSTs were sub-classified into two subtypes: Sideways and Twisting. MSTs were sub-classified into four subtypes: Backward, Festination, Forward, and Wheeling. Because all 90-degree turns were FST, they were sub-classified into only two turn subtypes: Step and Spin.

2.4. Statistical analysis

Alpha was set at 0.05 for all statistical tests. Data met criteria for normality and homogeneity of variance (Levene's test). Bonferroni corrected alpha values were applied when appropriate to minimize risk of multiple comparison bias. Tukey's tests were used for post-hoc comparisons. Unpaired *t*-tests were used to compare data between PD and controls for all clinical scales except the UPDRS-III, which was completed only for PD-ON and PD-OFF, requiring paired *t*-tests. MoCA and ABC scores were not available for one of the controls so their information was omitted from the analysis. To ensure accuracy in video analysis, an inter-rater reliability assessment was performed on the 180 degree turn data using Cohen's kappa statistic and yielded an acceptable inter-rater agreement of 0.814 for turn classifications. To evaluate turn strategies, the mean number of turns of each classification subtype was converted into a mean percentage of turns per subtype. For 180-degree turns, the mean percentages of turns per subtype were analyzed using ANOVAs with Turn Subtype as the within-subject variable and Group as the between-subject variable. For 90-degree turns, there were only two possible subtypes so only the percentage of Step-turns were presented in analysis, setting Task as the within-subject variable and Group as the between-subject variable.

3. Results

No differences were seen between PD participants (69.81 ± 6.91 yrs., female = 9.48%, height = 1.72 ± 0.08 m, weight = 77.78 ± 19.26 kg) and controls (66.19 ± 7.87 yrs., female = 12.81%, height = 1.75 ± 0.10 m, weight = 85.62 ± 17.12 kg) in terms of basic demographic information (Table 1).

3.1. Task 1: 180-degree turns

Data for the percentage of FSTs and MSTs by group for 180-degree turns are presented in Fig. 2(A). Results show significant differences across groups when comparing the percentage of FSTs and MSTs, suggesting a main effect of group: FST vs. MST $F(2, 55) = 9.578$, $p < .001$, $\eta_p^2 = 0.26$. Post-hoc tests indicated that PD-OFF performed significantly more MST than both controls ($p < .001$) and PD-ON ($p < .05$). There was no observable difference between PD-ON vs. controls ($p = .102$).

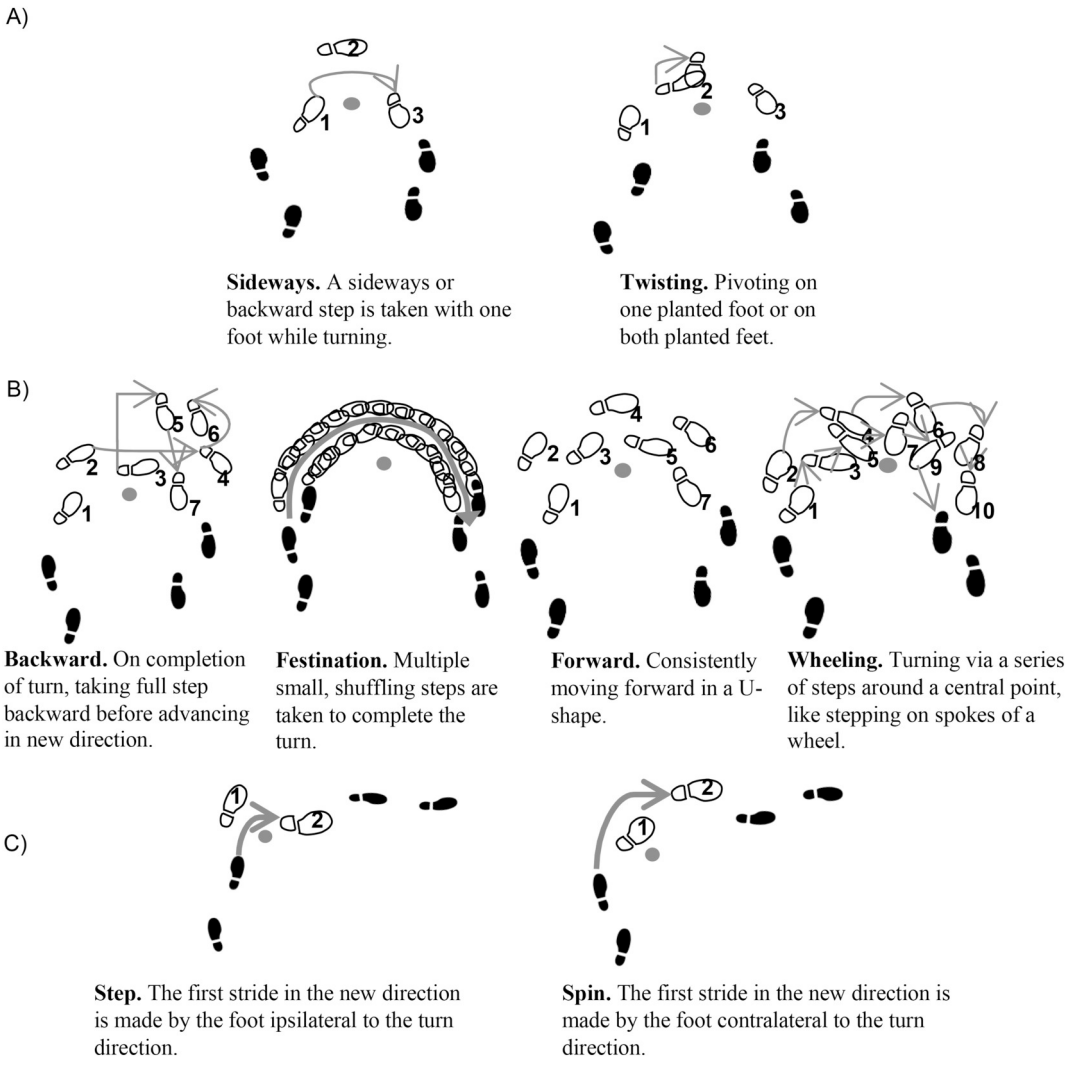

Fig. 1. Turning classification. 180-degree Few-step turns broken into Sideways and Twisting-turns (A); 180-degree Multi-step turns broken into Backward, Festination, Forward and Wheeling-turns (B); 90-degree turns broken into Step and Spin-turns (C). Definitions for classifying turn subtypes were adapted from Stack et al., (2004). Note: black-filled feet are walking steps and white-filled feet are turning steps.

Descriptive breakdown of FSTs and MSTs by turning subtype appears in Fig. 2 (B&C) and is presented as a mean percentage of turns per subtype. For FST, there was a significant effect of group on percentage of Twisting and Sideways-turns completed $F(4,108) = 4.600$, $p < .05$. Post-hoc analysis revealed that controls used significantly more Twisting-turns than PD-OFF ($p < .05$; Fig. 2B); no significant difference was observed between PD-ON and PD-OFF ($p = .074$) or PD-ON and controls ($p = .450$). Additionally, no significant difference was observed between groups in the percentage of Sideways-turns (Fig. 2B).

When using MSTs, all groups favoured the more stable Forward-turn. Inspection of video data revealed that PD participants used a larger number of different turn strategies than controls, who used only a single subtype of MST (Forward-turns). The greatest number of subtypes observed was in the PD-OFF group, using all 4 MST subtypes. However, PD-ON did not use festination turns, and thus used only 3 different subtypes (Fig. 2C). Individual ANOVAs performed on each MST subtype (excluding Festination) revealed that while the total number of strategies used by each group differed, percentage of turns within each MST subtype did not differ across groups: Forward-turns $F(2,55) = 2.726$, $p = .074$; Backward-turns $t(20) = 0.5454$ $p = .592$; Wheeling-turns $t(20) = 0.8989$ $p = .379$. Controls were excluded from Backward and Wheeling-turn analysis as they did not utilize these subtypes.

3.2. Tasks 2–4: 90-degree turns

Data for the percentage of Step-turns, the most stable turning type used in 90-degree turning tasks, are presented in Fig. 3. There was a significant interaction between Task and Group ($p < .001$). Follow-up ANOVA's were performed across tasks for each group separately to determine the source of variation. Using a Bonferroni corrected alpha value of 0.016 there was a significant effect of tasks for the control group $F(2,45) = 8.666$, $p < .001$, $\eta_p^2 = 0.278$. Post-hoc analysis determined that the control's turning strategy changed from Task 3 to 4 – the tasks with unpredicted turns – in response to the cognitive load present in Task 4. With the secondary DT present, controls completed a greater number of step-turns (Fig. 3; $p < .05$). This turning strategy adaptation was not present for either PD-OFF $F(2,60) = 0.392$, $p = .678$ or PD-ON $F(2,60) = 0.805$, $p = .452$.

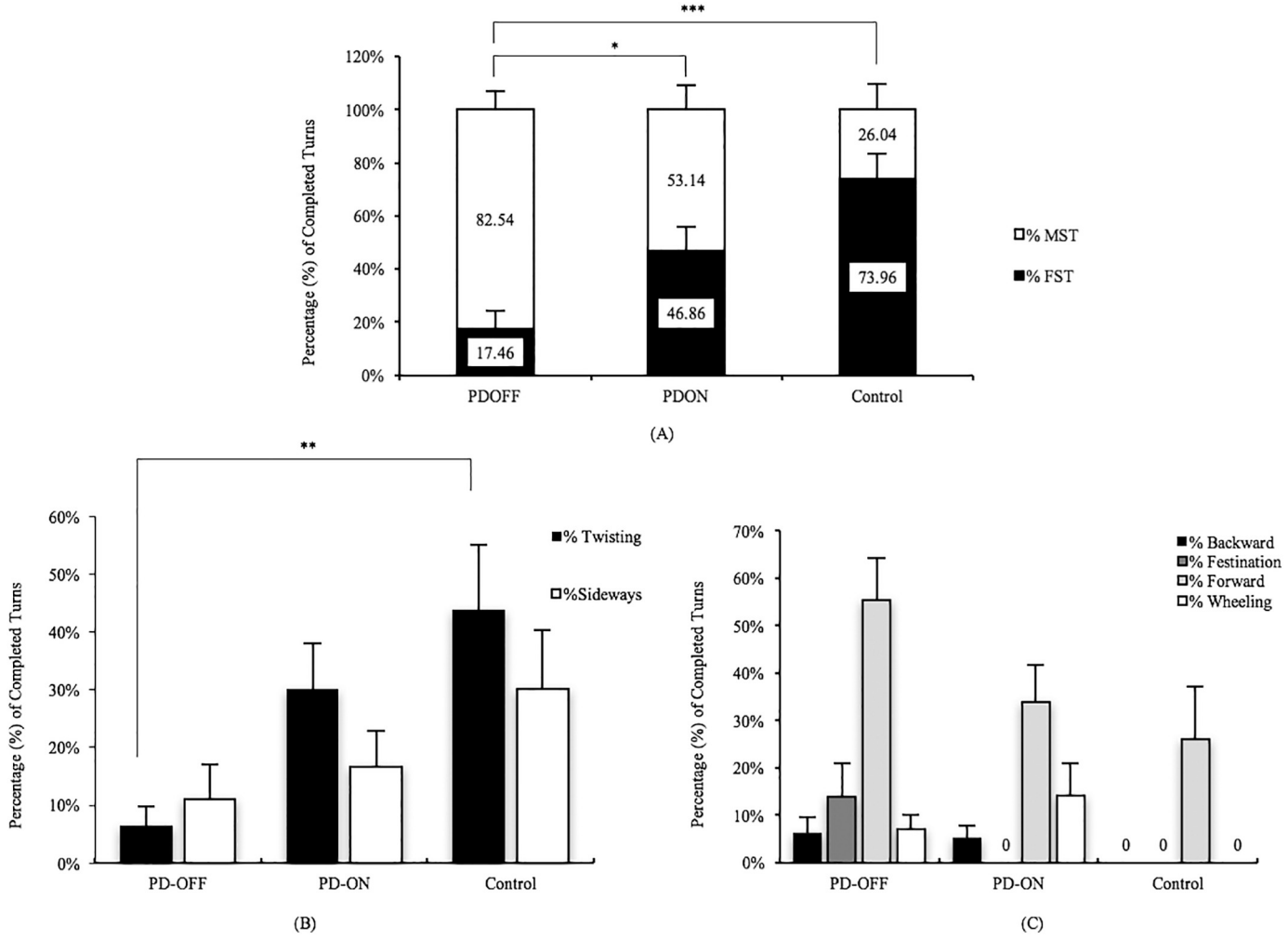

Fig. 2. Percentage of turning subtypes used in Task 1: Percentage of Few-step turns (FST) and Multi-step turns (MST) (A); FST breakdown into Twisting vs. Sideways-turns (B); MST breakdown into Backward, Festination, Forward and Wheeling-turns(C). *, $p < .05$; **, $p < .01$; ***, $p < .001$.

3.3. Fallers vs. Non-fallers

A 6-item questionnaire was provided to each participant that modeled the questions asked by the movement disorder specialist in clinic. It was found that fallers are the only group that use festination turns, which consisted of 22.5% of their turning strategies (Table 3.). The forward subtype was utilized by all three groups; however, the other three MST subtypes were only utilized by the PD group. Further, these subtypes were more heavily used in the Fallers group, when compared to non-fallers – with festination turns only being seen in the fallers group. When using MST, non-fallers favoured the forward turning subtype, while rarely using backward and festination turns.

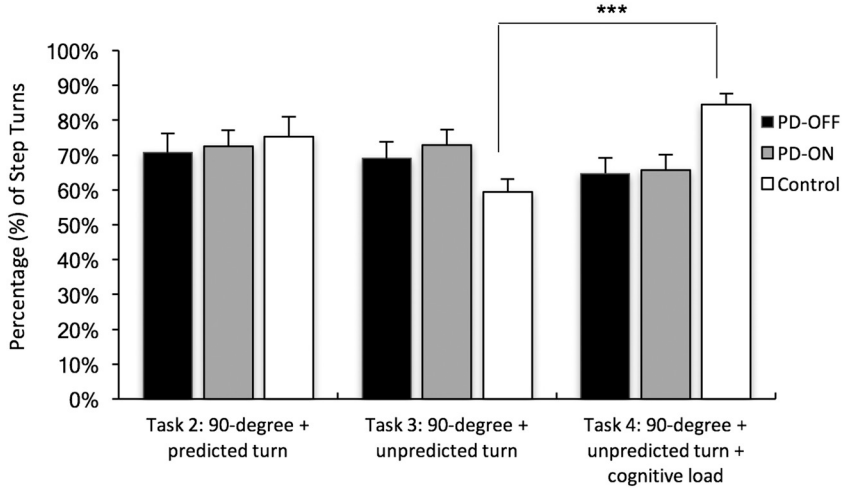

Fig. 3. Percentage of Step turns completed in tasks 2–4 by each group: ***, $p < .001$.

Table 3
Turn percentages for 180 degree turns. Data reported as a percentage of the total turns taken for each group.

Turn Type	PD-OFF		PD-ON		Control	
	Fallers	Non-Fallers	Fallers	Non-Fallers	Fallers	Non-Fallers
Forward (%)	38.0	66.7	31.3	47.2	33.3	24.3
Backward (%)	5.6	9.7	4.7	4.2	0.0	0.0
Festination (%)	22.5	0.0	0.0	0.0	0.0	0.0
Wheeling (%)	22.5	4.2	21.9	2.8	0.0	0.0
Twisting (%)	2.3	8.3	35.9	22.2	55.6	41.0
Sideways (%)	8.5	11.1	6.3	23.6	11.1	34.6

Fallers in both the PD-ON and PD-OFF groups utilized similar turning strategies at similar proportions. PD-OFF Fallers used significantly more Festination turns compared to PD-OFF ($F(2,56) = 3.467(P < .015)$).

4. Discussion and conclusion

4.1. 80-degree turn strategies

The current findings are consistent with previous studies which demonstrate that individuals with PD required more multi-step turns [3,17,19]. However, in contrast with previous studies which report differences as a function of disease status (PD vs. control), our novel finding suggests that these turning differences emerge as a function of medication status. In the present study, PD-OFF produced significantly more MSTs than both PD-ON and controls. This suggests that medication may influence turning by lowering step-number and altering turning strategy selection and execution.

Few studies have investigated the influence of medication status on 180-degree turns in PD [12,13]. Hong and Earhart (2010) reported that, although not significant, individuals with PD produced fewer steps while turning in 'ON' vs. 'OFF' medication states. In a second study, investigators assessed the effects of medication on turning in PD participants with and without FOG while completing static 180-degree turning tasks [13]. Results suggested that PD-ON participants without FOG had faster walking speeds, shorter turn-duration and used fewer steps while turning when compared to 'OFF' state; however, even in 'ON' state, PD participants without FOG still remained impaired vs. controls [13]. Methodological discrepancies in the analysis of turning patterns may partially explain conflicting results between studies. These studies compared turning strategy by analyzing the step number used within turns. In the present study, turning strategy was investigated by classifying turns into distinct subtypes. This classification may expose turning differences not apparent when solely quantifying the number of steps taken within a turn.

Closer examination of data revealed that turning patterns differed across groups (Fig. 2). To further understand how turning patterns differ between PD and controls, we used a unique turning classification system adapted from Stack and colleges (2004). This novel system extended the broad division of turns into FSTs and MSTs to investigate specific 180-degree and 90-degree turn strategies used within these categories. In the current study, individuals with PD used an increased number of different turning strategies compared to controls; this finding was most prevalent for PD-OFF.

All groups favoured the more stable Forward-turn when completing MSTs. Controls exclusively used this turn subtype when performing MSTs, suggesting that reducing variability and utilizing a unified strategy – specifically the Forward turn – may be a more "normal" pattern of turning strategy. Another possible, although less likely, explanation for the high proportion of Forward-turns is that controls overall produced fewer MSTs compared to FSTs and thus had less need to utilize all MST subtypes.

The present study suggests that there may be a specific effect of levodopa on turning strategies utilized by individuals with PD. Collectively, findings within 180-degree turns indicate that a crucial difference in turning between controls vs. PD is the inability to adopt a unified turning strategy. This increased variability of turning strategy appears to be exacerbated in PD-OFF. It is possible that the lack of uniformity in turning strategies may contribute to the increased fall risk observed in PD. This is consistent with previous literature which suggests that implementing specific turning strategies may improve postural stability and reduce fall risk [20]. This is further explained by Mellone et al. (2016), who suggest that individuals with PD delay turn initiation compared to controls [21]. When coupled with our results, these findings suggest that individuals with PD may require more time to formulate a specific motor plan and are unable to correctly modify that plan once selected.

Analyses of each MST subtype across groups revealed that only the frequency of Festination-turns was significantly different, occurring solely in the PD-OFF group. This is contrary to previous findings that reported Festination-turns were only used in PD participants in the 'OFF' medication state who experienced FOG [22]. None of the current study participants had clinical evidence of FOG nor did they experience FOG during daily activities. Nanhoe-Mahabier et al. (2011) did not examine PD participants in the 'ON' medication state, and it is thus possible that the use of Festination-turns may not be due to the presence of FOG, but rather a consequence of the 'OFF' medication state.

4.2. 90-Degree turn strategies

Few studies have examined 90-degree turns in individuals with PD vs. controls [23] and to the authors' knowledge no prior studies have assessed the effect of medication and DT on these turns. Interestingly, our analysis revealed that only controls made an adaptation toward a steadier turn subtype (i.e., more Step-turns vs. Spin-turns) when presented with increasing task demands during 90-degree turns. Controls initially switched to a Spin-turn strategy (e.g., less stable) when encountering the first 90-degree task load – that is, predicted vs. unpredicted turns seen in Tasks 2 and 3, respectively. This may reflect the desire for controls to generate a faster turn in response to the verbal cue given in Task 3. However, when the cognitive DT was introduced to the unpredicted turn, controls overwhelmingly switched back to the more stable Step-turn. Importantly, neither PD-OFF nor PD-ON altered their proportion of Step-turns across tasks, suggesting they did not adapt turning strategy with increasing task complexity. No scores were created to reflect accuracy in the secondary counting task. The goal of the cognitive DT was to provide an additional load to the turning tasks and was not to correlate cognitive performance with turning strategy, as the degree of error made during the task would be difficult to associate with

the turning type used. This may be a finer point to consider in future studies.

A potential weakness of the current study is that data were collected in a single visit for each participant. This may have resulted in fatigue onset for some later tasks in the PD-ON group. It is possible that fatigue may have altered turning patterns observed in PD participants when 'OFF' vs. 'ON' medication. Another limitation of the current study is the conversion of turning scores into percentages. Because turn types were observed as counts, and not continuous data, a non-parametric statistical test may have been more appropriate for analysis.

4.3. Clinical relevance

Turning alterations can often be visually observed as an early clinical sign of potential gait dysfunction in PD. The current work expands upon this observation and demonstrates that turning strategy could be assessed in a simple video-recording and categorization method that is easily reproducible in a clinical or rehabilitation setting. These results also help inform regarding the potential nature of turning impairments in PD. In the current study, the effect of medication status was most prominent in the 180-degree turn task, with PD-OFF producing more MSTs and a larger number of different turn subtypes. Turning strategy was also affected in 90-degree turns for PD participants, manifesting as an inability to adapt turning strategy when introduced to a cognitive DT. These results suggest that failure in selecting consistent turning strategies may be a specific functional impairment associated with turning in PD. In a dynamic view of motor control, alterations in motor behaviour emerge due to constraints in the task, subject and environment [24]. It is possible that the observed variability in turning strategies utilized by PD participants is a mechanism to adjust for perturbations related to the disease and DT. The current study suggests individuals with PD could reduce fall risk via the development of a less variable repertoire of turning strategies; the festination turning strategy should be avoided while the forward turn strategy should be favoured. We propose that rehabilitation efforts should focus not only on number of steps used to complete turns, but also reducing the variability in turning strategy. Further, as suggested in gait literature, rehabilitation programs addressing turning in PD may benefit from using paradigms that involve DT to simulate typical adaptations in turning strategy that may be required for ambulation during daily activities.

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