Effects of Parkinson's Disease and a Secondary Cognitive Task on Standing Postural Stability

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Abstract With recent successes in characterizing standing postural stability of people with neurological disorders, Time-to-Boundary (TTB) measures have potential to provide deeper insights into the impacts of Parkinson's disease (PD) and dual tasking on postural control. The TTB captures the critical relationship between the body sway and base of support, not incorporated into traditional stability measures. However, few studies have evaluated TTB in people with PD. The purpose of this study is to extend the existing work on how PD and a distracting cognitive task impacts standing postural stability. Different TTB measures were applied to data from fourteen PD and thirteen neurotypical adults (NA) subjects. Our results indicate that TTB measures are significantly worse in PD than NA subjects regardless of the existence of a secondary cognitive task. Further, medio-lateral TTB (but not anterior-posterior or 2-dimensional) was significantly negatively affected by the secondary cognitive task in both PD and NA groups.

1 Introduction

According to Marras et al. [1], the estimated number of people with Parkinson's disease (PwPD) in the US in 2020 is nearly 930,000. Importantly, compromised balance control is a major cause of chronic disability in PwPD. Preliminary studies have also shown that PwPD have abnormal body sway that links to falls [2]. Thus, studying the postural balance control of PwPD can improve our understanding of fall risks in this population.

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On a daily basis, completing postural and cognitive tasks at the same time is ubiquitous, and these two tasks together often worsen the performance on one or both tasks. This “dual-task interference” (DTI) suggests a partial overlap between neural structures contributing to control of postural and cognitive tasks. Such dual tasking is particularly difficult for PwPD and has been suggested to be related to falls in this population [3].

Given the influence of DTI and body sway on falls in PwPD, several studies have related effects of a secondary cognitive task on PwPD [4, 5]. However, reported results are somewhat inconsistent across different sway measures. This might be because the traditional measures used in those studies (e.g., sway velocity or total excursion) did not account for the relationship between body’s sway and its base of support (BOS) whereas this relationship is fundamental in balance control.

To cope with this limitation of the traditional measures, a relatively new multi-dimensional measure of postural control was developed, called Time-to-Boundary (TTB) [6]. Although this measure has been applied to characterize neurological disorders such as multiple sclerosis, only a few PD studies have utilized this measure. One study by van Wegen et al. demonstrated that PwPD have smaller medio-lateral (ML) TTB compared to neurotypical adults (NA) [6]. Another one by Workman et al. reported slight effect of a secondary cognitive task on anterior-posterior (AP) TTB in PwPD [5]. However, the effect of dual tasking on ML TTB has not been evaluated.

The purpose of this study is to further examine the effects of PD and a secondary cognitive task on the standing postural stability using different TTB measures. A better understanding of how those conditions impact postural control would provide a better predictor of fall risks in PwPD. Also, this understanding could contribute to the development of new therapeutic training or assistive devices to help prevent falls in PwPD.

2 Material and Methods

2.1 Subjects

Fourteen PD and thirteen NA subjects participated in this study. The mean age and standard deviation (in parenthesis) of PD and NA subjects are 72.61 (60.4) and 69.81 (7.55), respectively. The subjects were also free of any biomechanical injuries or neurological conditions other than PD impacting balance. The methods used in this study was approved by the Institutional Review Board of Arizona State University. Prior to the experiment, all subjects provided informed consent.

Table 1 Mean and standard deviations (in parentheses) of TTB measures

Measures		Single task	Dual task
2D TTB (s)	NA	13.22 (3.80)	12.78 (2.88)
	PD	9.78 (3.46)	9.76 (4.16)
AP TTB (s)	NA	17.88 (6.26)	17.65 (4.86)
	PD	13.79 (5.43)	13.94 (5.49)
ML TTB (s)	NA	71.80 (19.60)	63.22 (17.12)
	PD	53.40 (20.92)	45.16 (20.42)

2.2 Instrumentation

An instrumented treadmill system with two integrated force plates, a motion capture system, a headphone, and a microphone were utilized. The treadmill system (Motek-force Link, Amsterdam, Netherlands) was used to measure the center of pressure (COP) under separate foot of every subject, whereas the motion capture system (VICON, New York, USA) was used to capture the motion of markers placed on specific positions on subjects. Vicon Nexus 2.2 was used to synchronize the data from these two systems. Earbuds and a microphone were utilized to generate auditory stimulus and to capture the verbal response from the subjects (Table 1).

2.3 Protocol

The quiet stance experiment contained two tasks, namely single-task and dual-task. During standing, the subjects wore shoes and placed their feet on separate force platforms, with a heel-to-heel distance of 10 cm. In addition to standing, the subjects were required to complete an additional cognitive task in the dual-task trials. For the cognitive task, the auditory Stroop task was chosen because it was reported as an effective and reliable method for raising cognitive load in PD subjects [7]. The stimuli, which were words "high" and "low" with corresponding tones, were delivered to the subjects via the earbuds. Subjects were instructed to quickly and accurately name the tone of the stimulus, while ignoring the word. The microphone stuck on the skin near their voice-box captured responses.

At least two practice trials were given to ensure the subjects understood the cognitive task. After that, they performed two single-task trials, followed by two dual-task trials. Each trial lasts 50 s. Between trials, a short break was given to reduce fatigue.

2.4 Data Processing

Force plate and auditory (microphone) data were sampled at 2000 Hz. Force-plate data were filtered with a low-pass 4th order Butterworth filter with the cut-off frequency of 7 Hz. In addition, the motion capture data was acquired at the sampling rate of 200 Hz for all subjects.

To serve the calculation of TTB, the net COP was calculated for all subjects based on Winter et al. [8].

2.5 Time-To-Boundary (TTB)

The geometric boundary (i.e., the shape of the BOS) was obtained using the motion capture data recorded by markers at heels, toes, and ankles. Three TTB measures, namely 2D TTB, AP TTB, and ML TTB, were then calculated based on the method adopted from van Wegan et al. [6].

2.6 Statistical Analysis

Normality of the data was first checked by the Shapiro-Wilk tests, followed by a 2-way repeated ANOVA to assess the effects of PD and the cognitive task on the TTB measures. All statistical tests were conducted using the SPSS statistical package (IBM, NY) at a level of $p < 0.05$.

3 Results

Regarding the group effect (i.e., NA versus PD), statistical significance was obtained for 2D TTB ($p = 0.019$) and ML TTB ($p = 0.012$), but not AP TTB ($p = 0.062$). For the task effect (i.e., single- versus dual-task), only ML TTB ($p = 0.024$) was statistically significant. For both groups, we observed reduced ML TTB during dual-task trials, where the ML TTB was the worst in combined PD/dual tasking. No interaction effects were observed in any TTB measures ($ps > 0.167$).

4 Discussion

This study demonstrated that TTB measures of PD subjects are consistently worse than those of NA subjects regardless of the task conditions, suggesting that PwPD are more unstable during standing balance compared to their NA peers.

No strong impact of the secondary cognitive task in the AP TTB was also confirmed, which is consistent with the previous work on AP TTB by Workman and Thrasher [5].

However, contrary to the results in AP TTB, this study showed that the secondary cognitive task significantly deteriorates ML TTB. This could be due to the prioritization of postural control in the sagittal over frontal plane, making the subject more unstable in the ML direction. Interestingly, even though we utilized different measures compared to Bekkers et al. (total excursion & root-mean-square of COP trajectory) [4], we consistently conclude that an addition of a secondary cognitive task has more impact on stability in the ML than the AP direction in PwPD and NA.

5 Conclusion

This study demonstrates that PD and has negative impacts on standing postural stability. Our results also suggest that ML TTB can be utilized as a sensitive measure to investigate the impact of the secondary cognitive task on standing postural stability. Future work is warranted to determine its relationship to falls in PwPD.

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References

1. C. Marras et al., Prevalence of Parkinson's disease across North America. npj Parkinson's Dis. **4**, 21 (2018).
2. A. Ashburn et al., A community-dwelling sample of people with Parkinson's disease: characteristics of fallers and non-fallers. Age Age. **30**(1), 47–52 (2001)
3. S. Heinzel et al., Motor dual-tasking deficits predict falls in Parkinson's disease: a prospective study. Parkinsonism Relat. Disord. **26**, 73–77 (2016)
4. E.M.J. Bekkers et al., The impact of dual-tasking on postural stability in people with Parkinson's disease with and without freezing of gait. Neurorehabil Neural Repair **32**(2), 166–174 (2018)
5. C.D. Workman, T.A. Thrasher, The influence of dopaminergic medication on balance automaticity in Parkinson's disease. Gait Posture **70**, 98–103 (2019)
6. E.E. van Wegen et al., Stability boundaries and lateral postural control in parkinson's disease. Mot. Control **5**(3), 254–269 (2001)

7. M. Mancini et al., Postural sway as a marker of progression in Parkinson's disease: a pilot longitudinal study. Gait Posture **36**(3), 471–476 (2012)
8. D.A. Winter, Human balance and posture control during standing and walking. Gait Posture **3**(4), 193–214 (1995)