The Effects of Task Prioritization on Dual-Tasking Postural Control in Patients With Parkinson Disease Who Have Different Postural Impairments

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Abstract

Objective: To investigate the effect of task prioritization on dual-task control in Parkinson disease (PD) associated with different postural impairments.

Design: Cross-sectional study. Participants were instructed to keep 2 interlocking rings apart and maintain balance in a tandem stance. Attention was focused on either stance stability (posture-focus strategy) or the interlocking rings (supraposture-focus strategy).

Setting: University research laboratory.

Participants: Fifteen patients with PD and less postural impairment and 15 patients with PD and more postural impairment (N = 30).

Interventions: Not applicable.

Main Outcome Measures: Postural sway, postural determinism (%DET), ankle co-contraction, and ring-touching time.

Results: In the less-impairment group, the supraposture-focus strategy provided smaller postural sway and postural %DET compared with the posture-focus strategy. In the more-impairment group, task prioritization showed lower effect on both postural sway and postural %DET. The supraposture-focus strategy led to less ankle co-contraction than the posture-focus strategy in the more-impairment group, but task prioritization did not affect ankle co-contraction in the less-impairment group. In both groups, the supraposture-focus strategy led to less ring-touching time than the posture-focus strategy.

Conclusions: The supraposture-focus strategy provided better dual-task control than the posture-focus strategy in both PD groups. In the less-impairment group, the supraposture-focus strategy enhanced postural automaticity and postural stability. In the more-impairment group, the supraposture-focus strategy reduced ankle stiffness, owing to reduced muscle co-contraction.

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A dual-task condition requires the execution of 2 tasks simultaneously. Specifically, for a postural-suprapostural dual task, one must maintain postural balance (postural task) and execute another task (suprapostural task) at the same time. Each task requires an appropriate allocation of attentional resources. However, humans have limited attentional capacity. Therefore, under challenging dual-task conditions, individuals typically prioritize one of the tasks. Because of reduced processing resources and defective basal ganglia mechanisms, patients with Parkinson disease (PD) have impaired dual-tasking postural control, and thus, tend to fall down in dual-task situations. Consequently, in dual-task conditions, it is recommended that patients with PD should focus on posture for the sake of safety. However, focusing on posture does not necessarily improve...
postural stability. Indeed, this focus might even cause a deterioration of postural automaticity or flexibility. This notion was tested in studies on healthy older adults and patients with early-stage PD without clinically observed postural symptoms. Individuals were tested by standing on a mobile platform and executing a force-matching task concurrently. The studies found that prioritizing posture resulted in worse suprapostural accuracy, postural stability, and postural automaticity compared with prioritizing supraposture.4,5

Yogeves-Seligmann et al. proposed a “task prioritization model.”6 They suggested that individuals with high postural control ability can prioritize the suprapostural task without causing deteriorating postural stability. In contrast, individuals with low postural control ability should focus on posture to minimize postural sway, even when the postural task is not very demanding. Therefore, the optimal task prioritization strategy for patients with PD might depend on the individual’s postural ability. In order to keep postural stability, individuals may use a strategy of devoting more attention to posture, or increasing muscle co-contraction level to stiffen a joint.7 It has been reported that older adults or individuals with postural impairment tended to pay more attention to posture for maintaining postural stability, resulting in higher ankle co-contraction and postural regularity when faced with balance challenges.7 Co-contraction would lead to joint stiffness and is considered to be a compensatory strategy for postural deterioration.7,10 However, stiffening joints may not be an effective balance strategy and would deteriorate postural flexibility.10,11 On the other hand, devoting more attention to posture would impair automaticity of postural control, which could be measured by the level of postural regularity.7,5,7,14-16 Greater postural regularity was interpreted as lower postural automaticity.4,5,7,14-16

To our knowledge, the association between postural stability and ankle co-contraction or postural regularity has not been clarified for the task prioritization model. In the present study, we aimed to determine the effects of task prioritization on the performance of a dual task in PD with different postural ability, with emphasis on postural control mechanisms, such as postural regularity and ankle co-contraction. We hypothesized that (1) for PD with less postural impairment, focusing on supraposture would lead to superior dual-task control, with smaller values of postural sway, postural regularity, and ankle co-contraction, and (2) for PD with more postural impairment, focusing on posture would result in less postural sway with higher postural regularity and ankle co-contraction.

### List of abbreviations:

- ANOVA: analysis of variance
- AP: anterior-posterior
- CAI: co-activation index
- CoP: center-of-pressure
- DET: determinism
- EMG: electromyography
- MDS-UPDRS: MDS-sponsored Revision of the Unified Parkinson’s Disease Rating Scale
- ML: medial-lateral
- PD: Parkinson disease
- PF: posture-focus
- SF: supraposture-focus
- RMS: root mean square

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**Methods**

**Participants**

The study included 15 patients with PD and less postural impairment and 15 patients with PD and more postural impairment (Fig 1). The inclusion criteria for these PD groups were (1) a diagnosis of idiopathic PD, according to the United Kingdom PD Society Brain Bank clinical diagnostic criteria,17 (2) PD onset at age ≥40 years, (3) a Mini Mental State Examination score ≥26 points, and (4) the score of item 3.10 (gait) and item 3.12 (postural instability) of the MDS-sponsored Revision of the Unified Parkinson’s Disease Rating Scale (MDS-UPDRS) <4 points.18 Items 3.10 and 3.12 of the MDS-UPDRS are scored from 0 to 4. A score of 4 on either item 3.10 or item 3.12 indicates that a patient’s posture is very unstable and that it is unsafe for that patient to perform a dual task. On the other hand, the MDS-UPDRS was used to define postural impairment. Less postural impairment was defined as a score of 1 on both item 3.10 (gait) and item 3.12 (postural instability), or a score of 0 on one and a score of 1 on the other. More postural impairment was defined as a score >1 on either the gait item or the postural stability item. Participants were excluded when they had any of the following: (1) history of brain surgery, (2) other diseases and/or conditions that could influence balance, or (3) action or postural tremors.

A priori sample size calculation was performed using data presented previously indicating a sample size of 28 participants (14 participants for each group) was sufficient to detect effects of task prioritization on dual-task performance in PD (Cohen’s d = 0.56, power = 0.8, α = 0.05). All procedures in the experiment were approved by the National Taiwan University Hospital Research Ethics Committee (Clinical Trial Registration No.: NCT03298503). Written informed consent was obtained from all participants.

**Experimental setup and conditions**

The participants were instructed to stand in a tandem stance on a Kistler force plate,4 with the more affected leg behind the other leg, and control 2 interlocking rings (suprapostural task) (supplemental fig S1, available online only at http://www.archives-pmr.org/). The more affected leg was defined as the side of lower extremity with higher sum of scores for items 3.3 (rigidity), 3.7 (toe tapping), 3.8 (leg agility), and 3.17 (rest tremor amplitude) from the MDS-UPDRS. For the suprapostural task, participants held 2 sticks steady in front of the body with the elbow in 90° flexion. Each stick had a metal ring with a diameter of 4 cm attached to the end, and the rings were interlocked.19 Participants were asked to prevent the 2 rings from touching each other. When the rings touched each other, a small voltage was recorded by a USB-6221 data acquisition device.5 To investigate muscle co-contraction in the ankle joint during the tandem stance, we placed surface electromyography (EMG) electrodes5 on the more affected leg (the rear leg) to record the activation of the tibialis anterior, soleus, peroneus longus, and medial gastrocnemius muscles (see supplemental fig S1), because the rear leg bore more body weight and had greater muscle activity than the front leg under tandem stance.20,21 All behaviors and EMG data were synchronized and digitized at a sample rate of 1 kHz.

All clinical assessments and dual-task examinations were performed in the morning, at least 12 hours after the last
administration of anti-Parkinsonian medications (medication-off test). All participants performed the dual-task with the posture-focus (PF) strategy and with the supraposture-focus (SF) strategy. To direct the attention to focus on postural or suprapostural tasks, we used the optimum-maximum method to provide specific task prioritization instructions for the primary and secondary tasks.\(^{22}\) In the PF condition, participants were instructed to pay most attention to the postural task (primary task), by maintaining a posture as stable as possible for the entire trial, and then, to perform their best on the suprapostural task (secondary task), by preventing the 2 rings from touching. In the SF condition, participants were instructed to pay most attention to the suprapostural task (primary task), by preventing the 2 rings from touching, and then, to perform their best on the postural task (secondary task), by maintaining a stable posture. There were eight 30-second trials in each experimental condition. The PF and SF strategies were randomly allocated to participants in each PD group.

**Data analysis**

For the suprapostural task, performance was based on the total time that the rings touched in each trial (ring-touching time). To assess postural parameters, the center-of-pressure (CoP) data were low-pass filtered at 6 Hz. The root mean square (RMS) of the CoP in the anterior-posterior (AP) and medial-lateral (ML) directions represented the amplitude of postural sway. In addition, we performed a recurrence quantification analysis to quantify the temporal dynamics of CoP motions.\(^{13,16,23}\) In the recurrence quantification analysis, the parameter of determinism (%DET) was used to quantify the predictability of the postural dynamic system, and greater %DET of CoP data indicates the postural dynamics is more regular, implying that postural control was less automatic.\(^{16,24,25}\) For detailed %DET information, please refer to supplemental appendix S1 (available online only at http://www.archives-pmr.org/). For the EMG analysis, the 30-second EMG signals were detrended and band-pass filtered at 10 to 450 Hz. After that, the RMS values of each EMG channel were calculated to represent the amplitude muscle activity. The co-activation index (CAI) in the AP direction was based on EMG RMS values of the tibialis anterior and soleus muscles. The CAI in the ML direction was based on EMG RMS values of the peroneus longus and medial gastrocnemius muscles. The CAI was calculated as follows:\(^{26}\):

\[
\text{CAI} (\%) = \frac{\text{less active muscle}}{\text{more active muscle}} \times 100\%
\]

Signal processing of CoP and EMG data were performed with MATLAB v.R2012a.\(^{24}\) The primary outcomes were postural sway, postural %DET, and CAI, and the secondary outcome was ring-touching time.
Statistical analysis

The effects of task prioritization and group on the variables of postural (postural sway, postural %DET, and CAI of both ML and AP directions) and suprapostural (ring-touching time) tasks were examined with a 2×2 mixed analysis of variance (ANOVA). Post-hoc tests were performed to evaluate significant interaction effects. We performed the Simes test to avoid over-corrections associated with the Bonferroni test. With the Simes test, the type I error rate was exactly 0.05, when the elementary hypotheses were independent. Statistical analyses were performed with SPSS v.21. The level of significance was set at P<.05.

Results

Table 1 presents the participants’ demographic and clinical characteristics.

Postural sway

We examined postural sway in the ML and AP directions for the 2 groups under both the PF and SF conditions (fig 2A and B). The ANOVA results revealed that the size of postural sway in the ML direction was affected by the group and by the interaction between the prioritization and the group (group: F1,28 = 9.07, P = .005; prioritization: F1,28 = 1.19, P = .285; prioritization×group: F1,28 = 5.53, P = .026). The less-impairment group exhibited larger postural sway during the PF condition than during the SF condition (P = .022). In contrast, task prioritization did not affect postural sway in the more-impairment group (P = .380). The more-impairment group exhibited larger postural sway than the less-impairment group in both the PF (P = .037) and SF (P = .002) conditions. In contrast, postural sway in the AP direction was not affected by group (F1,28 = 0.04, P = .953), prioritization (F1,28 = 0.78, P = .391), or their interaction (F1,28 = 0.09, P = .773).

Postural determinism

Postural %DET in the ML direction (fig 2C) was affected by prioritization (F1,28 = 9.90, P = .004), group (F1,28 = 7.04, P = .013), and their interaction (F1,28 = 9.86, P = .004). A post-hoc analysis showed that the less-impairment group had greater postural %DET in the PF than in the SF condition (P<.001). In contrast, task prioritization did not affect postural %DET in the more-impairment group (P = .997). The less-impairment group had a smaller postural %DET in the SF condition than the more-impairment group (P = .002). The postural %DET in the AP direction (fig 2D) was not affected by group (F1,28 = 2.71, P = .115), prioritization (F1,28 = 0.44, P = .513), or their interaction (F1,28 = 0.80, P = .382).

CAI of ankle joint

Figure 3A and B display the CAI values for the 2 groups under the PF and SF conditions in the ML and AP directions. ANOVA results showed that the CAI in the ML direction was affected by group (F1,28 = 4.23, P = .049), prioritization (F1,28 = 5.36, P = .028), and their interaction (F1,28 = 4.75, P = .038). In the more-impairment group, the CAI was larger in the PF condition than in the SF condition (P = .004). Moreover, in the PF condition, the more-impairment group had greater CAIs than the less-impairment group (P = .013). However, in the AP direction, the CAI was not affected by prioritization (F1,28 = 0.50, P = .688), group (F1,28 = 0.01, P = .279), or their interaction (F1,28 = 0.63, P = .653).

Ring-touching time

The mean ring-touching time (fig 4) was not affected by prioritization×group interaction (F1,28 = 0.17, P = .682). However, the ANOVA results showed main effects of group (F1,28 = 4.27, P = .048) and prioritization (F1,28 = 7.55, P = .010). The ring-touching times were longer in the more-impairment group than in the less-impairment group, and they were longer in the PF condition than in the SF condition.

Discussion

The present study aimed to investigate how task prioritization influenced dual-task control among patients with PD that had less or more postural impairment. One key finding was that in the less-impairment group, the SF strategy facilitated posture control, evidenced by the reductions in postural sway and postural %DET (ie, greater postural automaticity). In the more-impairment group, the SF strategy reduced ankle co-contraction (ie, less stiffness) without deteriorating postural stability.

Previous studies on older adults and early-stage PD showed that postural automaticity or flexibility could be increased by shifting attention away from posture, under dual-task standing conditions. Furthermore, studies have shown that focusing on

Table 1 Demographics and characteristics of patients with less or more postural impairments in Parkinson disease

<table>
<thead>
<tr>
<th>Participant Characteristics</th>
<th>Less Impairment (n = 15)</th>
<th>More Impairment (n = 15)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>64.2±6.2</td>
<td>66.8±5.8</td>
<td>.25</td>
</tr>
<tr>
<td>Age range (y)</td>
<td>52.9-73.8</td>
<td>55.2-74.9</td>
<td></td>
</tr>
<tr>
<td>Sex (M/F), n</td>
<td>9/6</td>
<td>7/8</td>
<td></td>
</tr>
<tr>
<td>H&amp;Y stage (off medication)</td>
<td>1.3±0.5</td>
<td>2.7±0.3</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Disease duration (y)</td>
<td>4.8±2.1</td>
<td>6.6±3.7</td>
<td>.11</td>
</tr>
<tr>
<td>MMSE score</td>
<td>28.5±1.4</td>
<td>28.6±0.9</td>
<td>.89</td>
</tr>
<tr>
<td>UPDRS part III score (off medication)</td>
<td>27.6±6.8</td>
<td>29.5±19.9</td>
<td>.54</td>
</tr>
<tr>
<td>Sum of scores for items 3.10 and 3.12</td>
<td>1.53±0.6</td>
<td>3.4±0.8</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

Data are the mean ± standard deviation, unless otherwise indicated.

H&Y stage, Hoehn and Yahr stage; MMSE, Mini-Mental Status Examination; UPDRS, Unified Parkinson’s Disease Rating Scale.

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posture itself constrained the postural control system by interfering with automatic control processes that normally regulate postural balance, in both healthy individuals and patients with PD.28,29 The remarkable impact that prioritization had on postural control in patients with PD and less postural impairment might be attributable to a neurological compensatory mechanism of the modulation of dopamine synthesis.30,31 Data from positron emission tomography studies suggested that synaptic dopaminergic transmission was optimal in early-stage PD, because dopamine synthesis was upregulated and dopamine transporters were downregulated.31 This compensatory neural activity might enable continued operation of the postural control process regulated by the cortical-basal ganglia-cortical loop. This mechanism might also preserve postural facilitation in patients with PD and less postural impairment. However, disease progression, significant dopamine depletion, and impairments in cortical motor networks and attentional networks lead to deficits in postural automaticity.32 Indeed, compared with early-stage PD, advanced PD was associated with hyperactivation of the dorsolateral prefrontal cortex, premotor cortex, parietal cortex, and cerebellum when performing automatic movements. This phenomenon was considered a compensation mechanism for basal ganglia dysfunction.32 In addition, a functional magnetic resonance imaging study showed that less effective connectivity among presupplementary motor area, cingulate motor area, and cerebellum resulting in PD patients having difficulty in achieving automaticity.33 Therefore, defective

Fig 2   Effects of task prioritization on postural performance for the patients with PD and either less or more postural impairment. Postural sway in the ML direction (A); postural sway in the AP direction (B); postural %DET in the ML direction (C); and postural %DET in the AP direction (D). Data are the mean ± standard error. *P<.05, †P<.01.
postural automaticity in PD with more postural impairment destroyed the postural facilitation function, and caused the deterioration in dual-task control.

Regardless of task prioritization conditions, the more-impairment group had greater CAI values than the less-impairment group. To control standing posture, older adults and patients with neurological diseases tend to engage ankle muscle to maintain balance, which increases the joint stiffness. Nagai et al. found that increases in co-contraction were associated with increased postural sway while standing and reduced functional reach distance in older adults. That finding indicated that high muscle co-activation led to poor postural control. Inadequate postural strategies (eg, ankle and hip strategies) have often been reported in patients with PD that experience significant postural symptoms while maintaining upright balance. However, when confronting postural perturbation, early-stage PD tended to cause increases only in hip stiffness. In contrast, ankle control was similar to that observed in healthy controls. This finding might explain our observation that less ankle co-contraction was measured in the less-impairment group than in the more-impairment group.

On the other hand, task prioritization only affected ankle co-contraction in the more-impairment group. The CAI value was larger in the PF condition than in the SF condition. Although several previous studies did not show a clear relationship between ankle co-contraction and attention modulation, Wuehr et al. reported that, among patients with balance disorders, when participants were asked to pay attention to a suprapostural task, the level of ankle muscle co-contraction decreased, compared with that observed when focusing on standing balance. However, in healthy participants, although drawing attention away from posture led to improvements in postural stability, no significant effect was observed in muscle activity around the ankle joint. That finding suggested that, among individuals without or with less postural impairment, postural automaticity (ie, postural % DET) was responsible for the effect that attention had on postural control. In contrast, for individuals with prominent postural impairment and more deteriorated postural automaticity, the effect...
that attention had on postural control manifested as an ankle stiffening strategy.

Surprisingly, our results did not support the “task prioritization model,” which proposed that individuals with low postural control ability should prioritize posture when executing a dual task, even in conditions that do not threaten postural control. Studies that consider postural performance during task prioritization often refer to the amplitude of postural sway, walking speed, or step length. However, our results suggested that postural automaticity (postural %DET) and ankle co-contraction might provide more information on the intrinsic phenomena associated with postural control. The posture-motor dual-task paradigm described in the present study could potentially be used for evaluating postural automaticity in patients with PD. An inability to modulate the degree of postural automaticity by shifting the focus of attention could be an indicator of postural automaticity deterioration. Patients with impaired automaticity tend to develop a freezing gait pattern. The early detection of postural automaticity deficits and postural training might improve postural automaticity and dual-task control in patients with PD.

Study limitations

First, in addition to the ankle strategy, a hip strategy is required for maintaining postural equilibrium, particularly for tasks that challenge postural control in the ML direction. Thus, further study is required to measure the hip strategy to gain a more detailed understanding of task prioritization effects on postural control in patients with PD. Second, task prioritization effects might vary with task difficulty, particularly with tasks that impose a postural threat. Further studies are needed with different task difficulties to confirm the applicability of the SF strategy in patients with PD.

Conclusions

Dual-task deficits are common in patients with PD. With an appropriate attentional strategy, patients with PD might execute dual tasks more safely and accurately. Our present findings suggested that, for patients with PD and less postural impairment, the SF strategy could increase postural stability and automaticity and facilitate suprapostural performance (ie, achieve less ring-touching time in the present experimental paradigm). Additionally, we found that the SF strategy prevented excess muscular activity in the ankle joint, with better suprapostural performance, in the more-impairment group. These findings might be useful in the clinic, when fall prevention education is provided to assist patients with PD to increase the level of functional independence. Future research could examine whether applying different task-priorities, within a posture-motor dual-task paradigm, might be a practical approach for the early detection of defective postural automaticity.

Suppliers

a. Kistler.
c. BL-AE; B&L Engineering.
d. MATLAB, version R2012a; Mathworks.
e. SPSS Statistics, version 21; IBM Corp.

Keywords

Attention; Electromyography; Parkinson disease; Postural balance; Rehabilitation

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