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Adaptation of gait termination on a slippery surface in Parkinson's disease

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ABSTRACT

Parkinson's disease (PD) causes instability and difficulty adapting to changing environmental and task demands. We examined the effects of PD on the adaptation of gait termination (GT) on a slippery surface under unexpected and cued circumstances. An unexpected slip perturbation during GT was followed by a slip perturbation during GT under two conditions: planned over multiple steps and cued one step prior to GT. Feed forward and feedback-based responses to the perturbation were compared to determine (1) how PD affects the ability to integrate adaptive feed forward and feedback-based GT strategies on a slippery surface, (2) if adaptations can be implemented when GT is required within one step, and (3) if behaviour changes with repeated exposure.

Similar to the control group ($n = 10$), the PD group ($n = 8$) adapted and integrated feed forward and feedback-based components of GT under both stop conditions. Feed forward adaptations included a shorter, wider step, and appropriate stability margin modifications. Feedback-based adaptations included a longer, wider subsequent step. When cued to stop quickly, both groups maintained most of these adaptations: foot angle at contact increased in the first cued stop but adapted with practice. The group with PD differed in their ability to adapt GT with slower, wider steps and less stability.

1. Introduction

Parkinson's disease (PD) is known to cause postural instability. Research has established that PD interferes with the integration of feed forward and feedback-based movements [1,2] and that a perturbation causing backward displacement, such as a slip, is destabilizing for someone with PD [2,3]. PD has also been shown to affect the ability to quickly change motor programs [4–6]. Neural impairments caused by PD may limit the ability to switch between walking and stopping or to develop the feed forward adjustments required to maintain stability while stopping gait on a slippery surface [7]. Neurodegeneration caused by PD may further limit the ability to adapt behaviour when stopping on a slippery surface: the striatum, along with the cerebellum and select frontal lobe regions, is involved in motor learning and adaptation [8–10] as well as on-line modification of movements [10] like those seen during anticipation of a perturbation.

Previous gait termination (GT) research in healthy participants reveals that adaptations to a known slippery surface include modifications in both feed forward and feedback-based movements. Feed forward adaptations include shorter steps onto the slippery surface [11–16], an increased stability margin [11,17], a forward centre of mass (COM) shift [11,18–20] and a decreased foot-floor angle to reduce shear contact forces [11–14,16,17,20]. Adaptations to feedback-based responses include increases in the subsequent step length [17,19,21,22] and a more stable COM–base of support (BOS) relationship [12,19].

While the ability of someone with PD to voluntarily adapt gait [23,24] and sit-to-stand movements [25] has been shown to be similar to controls, neither the greater challenge of GT nor the added difficulty of responding to an external perturbation like a slip has been examined. Past research has shown that participants with PD are able to integrate a feedback-based response while stopping on an unexpected, slippery surface [7]. This study, however, presents one of the first investigations into the *adaptation* of GT on a slippery surface in PD and addresses the following questions: (1) Can someone with PD integrate feed forward and feedback-based strategies to stop on a slippery surface? (2) Can this integration be implemented within one step? (3) If not, can someone with PD adapt movements with repeated attempts to stop within one step? Adaptive behaviours were examined by comparing an unexpected slippery stop to subsequent planned stops on the slippery surface. Following a series of planned stops, cued stops were elicited requiring GT within one step. The cued stops examined the ability to quickly generate

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adaptive behaviours. In the absence of adaptations, repeated exposure to the cued stops examined whether additional experiences enabled further adaptation.

We hypothesized that subjects with PD would have difficulty integrating the feed forward and feedback-based strategies required to adapt both planned and cued GT on a slippery surface and would require more experiences than healthy controls to show significant adaptations. Understanding the ability of someone with PD to adapt to changes in task demands would be useful in rehabilitation.

2. Methods

Participants included eight participants with idiopathic PD (66.0 ± 8.3 years SD) and ten age- and gender-matched controls (65.4 ± 7.3 years SD) (Table 1). All PD participants had taken their usual medication within 2 h of testing with no wearing off reported. The motor subscale of the Unified Parkinson's Disease Rating Scale was administered by a physiotherapist (range = 7–44). The severity of Parkinsonism was determined by a neurologist using the Hoehn and Yahr scale (range = 1–3). All participants walked independently and were free of orthopaedic, psychological, or other neurological disorders which could affect their ability to perform the tasks. All participants provided informed consent for protocols approved by institutional ethical review committees. The consent form stated that the surface may unexpectedly move when stepped on and participants were also given a verbal warning prior to signing the form.

All participants experienced three types of trials on a slippery surface in the following order: (1) one *unexpected slippery stop* which was cue done step prior to GT, (2) five *planned steps*on the slippery surface which were cued at the start of the trial, and (3) five *cued stops* on the slippery surface, introduced randomly across 15 walk-through trials, in which participants stopped on the slippery surface within one step.

Participants walked towards a set of lights at the end of the room which cued GT when illuminated. Without the cue, participants continued walking. The lights were controlled with an infrared light beam one step before the force plates in the middle of the room. To reduce anticipation, the unexpected slippery stop was elicited without knowledge of the perturbation after a series of cued stops on a non-slippery surface. In all cued stops, participants received the stop cue during the trailing limb step, stepped onto a force plate with their lead limb (first step), and completed GT (final step) by placing their trailing limb beside the lead limb. Starting location was manipulated so participants would naturally step on the force plate with their lead limb. To generate a slip perturbation, the unexpected slippery stop was elicited without knowledge of the perturbation after a series of cued stops on a non-slippery surface. In all cued stops, participants received the stop cue during the trailing limb step, stepped onto a force plate with their lead limb (first step), and completed GT (final step) by placing their trailing limb beside the lead limb. Starting location was manipulated so participants would naturally step on the force plate with their lead limb. To generate a slip perturbation, the force plate accelerated forward at contact for .15 m at an average of .47 m/s. This perturbation shares displacement and velocity characteristics with previous slip investigations [22,26].

Kinetic data were captured from custom-made force plates using a QNX data collection system (480 Hz sampling rate) and were used for identifying force plate movement. A high-resolution Motion Analysis System (Santa Rosa, CA) with seven cameras (60 Hz sampling rate), provided 3D coordinate information about body segment displacements. Markers were placed on anatomical landmarks including the xyphoid process and bilaterally on the ear, acromion process, olecranon, styloid process, anterior superior iliac crest, greater trochanter, lateral femoral condyle, lateral malleolus, heel, and fifth metatarsal head.

A 12-segment COM model was calculated using a custom-designed MATLAB program (Mathworks, Natick, MA) with data low-pass filtered at 6 Hz. Walking velocity was calculated at contact onto the force plate. Decreased velocity represented a feed forward adaptation. Step length and width were calculated from the heel markers of both feet. Step length was defined as the anterior–posterior (AP) distance from the trail limb heel to the lead limb heel. Step width was defined as the absolute medial–lateral (ML) distance between heels. Step parameter changes during the first step of GT represented feed forward adaptations: changes during the final step represented feedback-based adaptations. Foot dorsiflexion angle was calculated at contact on the force plate. A flatter foot decreases shear forces at contact and can be caused by a shortened step which brings the COM further forward. A flattened foot represented a feed forward adaptation despite a consistent frictional component in this paradigm.

A stability margin was calculated using an extrapolated COM position (xCOM) that includes both instantaneous COM height and velocity [27]. The difference between the xCOM position and the edge of the BOS represented the stability margin. The xCOM position incorporates the velocity of the COM allowing comparisons between groups moving at different speeds: the BOS edge was represented by the fifth metatarsal marker on the foot that was stepping. A smaller AP stability margin during the first step of GT reflected an anterior shift in the COM revealing a feed forward adaptation [12,18]. A larger lateral stability margin also reflected a feed forward adaptation. An increase in both stability margins during the final step reflected increased stability during the feedback-based component.

To investigate the ability of someone with PD to integrate feedforward and feedback-based adaptations, a RMANOVA (2 groups × 6 trials) compared the unexpected slippery stop to the series of five, planned stops. To determine if adaptations could be generated within one step and maintained across the cued stops, the final planned stop was compared to the five cued stops using a RMANOVA (2 groups × 6 trials). Significant trial effects were investigated with SNK post hoc analysis. Interactions were further investigated using a one-way ANOVA for each group. Statistical significance was set at $\alpha = .05$. Between group effect sizes (Cohen's *D*) were calculated and are presented in Table 2. Insufficient data caused two control participants (one from the unexpected slippery vs. planned stops, the other from the final planned vs. cued stops), and one PD group participant (walking velocity data only) to be removed from analysis.

3. Results

Both groups implemented feedforward and feedback-based strategies to stop on a slippery surface. PD affected walking speed and step parameters in all conditions, and stability when cued to stop within one step.

3.1. Unexpected slippery stop vs. planned stops

3.1.1. Feedforward adaptations

Both groups stepped significantly shorter and wider onto the force plate in the first planned stop and again in the second planned stop (step length: $F = 11.80$, $p < .0001$; step width: $F = 6.62$, $p < .0001$) (Fig. 1). Stability margins were also adapted during the planned stops (AP: $F = 23.23$, $p < .0001$; ML: $F = 6.67$, $p < .0001$): the AP stability margin decreased in the first planned stop and again in the second planned stop while the lateral stability margin increased in both the first and second planned stops. Walking velocity was not significantly different between trials ($F = 1.25$, $p = .297$).

Walking velocity was slower in the PD group (.96 m/s) compared to the control group (1.35 m/s) ($F = 16.96$, $p = .001$). The only group difference for the step and stability parameters was a shorter first step of GT in the PD group ($F = 5.82$, $p = .0291$) (Fig. 1) with no significant differences between groups for step width ($F = 2.72$, $p = .1196$) or stability margin (AP: $F = .86$, $p = .3697$; ML: $F = 3.08$, $p = .0996$).

Table 1
Participant characteristics for PD group.

ID	Age	Gender	PD duration	UPDRS	H & Y	Daily medication
PD1	71	M	9 years	31.5	2.5	Carbidopa/levodopa (250 mg ×7), Sinemet (250 mg (50/200) ×1), Comtam (200 mg ×6), Propranol (20 mg ×7)
PD2	68	M	6 years	36	2	Sinemet CR (250 mg ×3), Requip (2 mg ×3), Atenolol (25 mg ×1)
PD3	62	F	10 years	42.5	2	Sinemet CR (125 mg (25/100) ×2), Mirapex (.5 mg ×3)
PD4	51	M	11 years	36.5	2	Sinemet (125 mg (25/100) every 90 min), Requip (2 mg ×3), Amantadine (100 mg ×2)
PD5	78	M	8 years	44	3	Sinemet CR (×4), Requip (×3)[a]
PD6	63	F	13 years	7	1	Sinemet (125 mg (25/100) ×2–4), Mirapex (50 mg ×4–6), Amantadine (100 mg ×2), Stalevo (50 mg ×5)
PD7	73	M	8 years	29	2	Sinemet CR (125 mg (25/100) ×3), Mirapex (.5 mg ×3)
PD8	62	M	9 years	24	2	Sinemet CR (125 mg (25/100) ×2), Mirapex (1 mg ×7 and .5 mg ×2), Comtan (200 mg (1 tablet) ×7, 100 mg (.5 tablet) ×3)

[a] Dosage information is not available.