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Conflicting and non-conflicting visual cues lead to error in gait initiation and gait inhibition in individuals with freezing of gait

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ABSTRACT

Introduction: We asked whether conflicting visual cues influences gait initiation, gait inhibition and postural control in Parkinson's disease (PD) between freezers, non-freezers and healthy older adults.
Methods: Twenty-five PD participants on dopaminergic medication and 17 healthy older adults were asked to initiate or refrain gait depending on visual cues: green GO (GG), green STOP (GS), red GO (RG), red STOP (RS). Center of pressure (CoP) displacement, variability and mean velocity (VCoP) in the anterior-posterior (AP) and medial-lateral (ML) directions and movement time (MT) were measured.
Results: Gait initiation: Both freezers and non-freezers were different from controls in GG and GS. In GS, freezers had smaller CoP displacement and velocity in both directions ($p < 0.01$), while non-freezers had smaller VCoP in AP and ML ($p < 0.01$). AP CoP displacement in GS was smaller in freezers compared to non-freezers ($p < 0.05$). Freezers had longer MT compared to controls in GG and compared to both groups in GS ($p < 0.01$). *Gait inhibition:* Controls and freezers had larger CoP displacement variability ($p < 0.05$) and velocity ($p < 0.01$) in both directions in RG compared to RS. No differences were seen in non-freezers. Three freezers initiated walking during the RG or RS conditions.
Conclusion: Freezers were in general slower at initiating gait, displayed a more restrictive postural strategy and were more affected by the conflicting conditions compared to both controls and non-freezers. In freezers, the conflicting visual cues may have increased the cognitive load enough to provoke delays in processing the visual information and implementing the appropriate motor program.

1. Background

Along with turning and walking into narrow spaces such as doorways, gait initiation (GI) is known as one of the main triggers of freezing of gait (FoG). The asymmetric nature of GI and the complex interplay between postural stability and locomotion [1] could explain the highest occurrence of FoG in GI compared to steady state walking. As FoG has been associated with high risks of postural instability, falls and gait asymmetry [2–5], controlling postural stability during GI could interfere with the stepping activity in individuals with FoG.

Anticipatory postural adjustments (APAs) are critical to prepare GI, and were reported to be smaller and slower in PD compared to healthy older adults [6,7], due to deficits in posture-locomotion coupling [1,8]. Furthermore, absence of APAs and disruption of spatial-temporal coordination between the APAs and the actual stepping have been associated with FoG [6,8,9]. Cognitive functions also play a main role in GI. Although the underlying mechanisms are still not well understood freezers and individuals with postural instability and gait disturbances may be at higher risks of developing mild cognitive impairments (MCI) as well as dementia compared to tremor dominant individuals [10–13]. FoG has also been strongly associated with deficits in visual-spatial processing and with structural deficits in executive functions, leading to impairments in set-shifting and inhibition function [14–18].

Using incongruous visual cues to assess the effect of age on step response inhibition, Sparto et al., [19,20] showed greater variability, more postural adjustment errors and step initiation latencies in older adults compared to younger adults [19]. The authors suggested that deficits in inhibitory function could affect decision processing and delay voluntary step responses [20]. Cohen et al.,

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[21], reported performance deficits in a Go-No-go task associated with inhibitory control in freezers compared to non-freezers. However, it is not known how conflicting visual cues would affect GI and inhibition in freezers and non-freezers. GI is an insightful model to assess postural mechanisms in older adults and in PD [19,22], and could provide insights regarding the association between postural instability, FoG and MCI in PD.

Our main objective is to compare GI and gait inhibition between healthy older adults, freezers and non-freezers when presented with conflicting and non-conflicting visual cues. We expect GI and postural stability in freezers to be more affected, i.e. showing slower GI or increased occurrence of FoG, in the conflicting cues compared to both non-freezers and older adults.

2. Methods

Twenty-five participants with PD and 17 healthy older adults (age:66.3 sd:9.5, 13 women) participated in the study. PD participants were recruited from the Parkinson's disease and Movement Disorders Clinic of the Ottawa Hospital Research Institute. Inclusion criteria: no history of orthopedic/musculoskeletal impairments, or neurological conditions other then Parkinson's disease that could impact balance and gait. Testing was performed in the optimally medicated state (dopaminergic medications). PD subjects were divided into freezer (age:69.5, sd:6.2, disease duration: 7.9y, sd:5.3y, n = 12, 1 women) and non-freezer (age: 62.9, sd: 10.8, disease duration: 5.4y, sd: 3.8y, n = 13, 2 women) according to the FOG questionnaire. Freezer had to report freezing "about once a week" or more. Controls were excluded if they reported previous surgeries and/or impairments that could interfere with gait and balance. The study was approved by our Institutional Review Board. Participants gave their written consent.

PD severity was assessed using the Unified Parkinson's Disease Rating Scale (UPDRS) III, (motor disability). Participants performed the Montreal Cognitive Assessment (MoCA) to determine MCI, i.e. scores below 26. Trail-making A and B were performed to assess executive function and cognitive flexibility.

Participants stood quietly on a force platform with their feet at a comfortable width and looking straight ahead at a large landscape (3 m x 4m) projected on a wall 15 m away. Following a visual cue, participants had to promptly initiate walking over 10 m or stay quietly on the force platform. Participants were presented with two non-conflicting and two conflicting cues. Adapted from the Stroop Colour and Word test, visual cues were as follow: Green Go (GG), Red Stop (RS), Green Stop (GS) and Red GO (RG). Participants were instructed to start walking when the green signals, GG and GS, were presented, and had to remain on the force platform for 30 s when presented with the red signals, RS and RG. Before each trial, participants were asked to "*get ready*", after which a 1 s to 5 s delay was randomly introduced before the projection of the visual cue. The order of the visual cues was randomized and performed twice.

2.1. Data acquisition and reduction

Ground reaction forces and moments were collected using one force platform (Kistler, Winterthur, Switzerland) recording at a sampling frequency of 200 Hz. Data were filtered with a zero-lag fourth-order Butterworth filter with a 10 Hz cut-off frequency. The time-varying position of the CoP under each foot was calculated using the orthogonal forces and moments on the force plate. The CoP displacement amplitude (in mm), CoP displacement root-mean-square (RMSCoP) and mean velocity (VCoP) (mm/s) were calculated in the anterior-posterior (AP) and medial-lateral (ML) directions. Movement time (MT), from the beginning of the anticipatory postural adjustments (APAs), to the toe off of the trailing leg, was determined for each GI trial.

2.2. Statistics

Mixed model for repeated measures were used to determine differences between groups and between conditions for postural stability during the RS and RG trials and for the GIs trials (GG, GS). Bonferroni post-hoc procedures were used. One-way ANOVAs were used to compare age and MoCA scores between the three groups and Student *t*-test were used to determine any difference for disease duration and UPDRS III between PD.

3. Results

Age between the three groups ($p = 0.21$) and disease duration ($p = 0.20$) between freezers and non-freezers were not different, Table 1. UPDRS III ($p = 0.003$), FoG-Q ($p < 0.001$) and trail-making B-A% ($p = 0.03$) were larger in freezers compared to non-freezers. MoCa was lower than 26 in six freezers and two non-freezers ($p = 0.07$). Five freezers reported one or more falls in the previous 3 months compared to 1 participant in non-freezers (fell once). Two freezers reported falling once, 2 reported falling twice and 1 reported falling three times. Two freezers started walking on the RG signal, one freezer went once on a RS signal and 3 freezers did not go on a GS signal. Non-freezers and controls performed the tasks as instructed.

3.1. Gait initiation

CoP displacement amplitude in the ML direction showed no main effect for condition $F(1, 35) = 0.514$, $p = 0.478$, while a main effect for group was found $F(2,35) = 39.46$, $p < 0.001$, Table 2. Multiple comparisons revealed larger CoP displacement amplitude in controls compared to freezers and non-freezers in GG and GS trials $p < 0.001$. No difference was seen between freezers and non-freezers. For the displacement amplitude in the AP direction, an interaction was shown between conditions and groups $F(2, 35) = 5.441$, $p = 0.009$. Multiple comparisons revealed larger displacement amplitude in controls compared to non-freezers in GG ($p = 0.04$) and compared to freezers in GS ($p = 0.007$). In the GS condition non-freezers had larger displacement amplitude compared to freezers ($p = 0.03$). Non-freezers showed larger displacement in GS compared to GG ($p = 0.03$). A main effect for group was seen for VCoP in ML $F(2,35) = 18.86$, $p < 0.001$. Controls were faster compared to freezers and non-freezers ($p < 0.001$). Controls had larger VCoP compared to freezers in GG ($p = 0.022$) and compared to both groups in GS ($p < 0.001$). No differences were seen between freezers and non-freezers ($p = 0.110$). A main effect for group was found in VCoP AP $F(2,35) = 10.88$, $p < 0.001$. Multiple comparisons showed faster displacement in controls compared to freezers and non-freezers during the GS trials ($p < 0.001$). No difference was seen between PD participants and no main effect was found for task.

Finally, movement time showed a task-group interaction $F(2,35) = 3.98$, $p = 0.028$. Freezers took more time during GG

Table 1
Freezing of gait (FoG) questionnaire, Montreal Cognitive Assessment (MoCA) and Trail Making B-A in freezers and non-freezers.

	Non-Freezers	Freezers	P values
FoG questionnaire	1.0 ± 1.0	9.7 ± 5.1	0.000
MoCA	27.0 ± 1.7	25.3 ± 3.4	0.071
Trail making B-A (s)	29 ± 23	70.3 ± 54.2	0.026
Trail making B-A (%)	201 ± 69.1	286.3 ± 134.4	0.066