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Impaired anticipatory control of grasp during obstacle crossing in Parkinson's disease

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ABSTRACT

During self-paced walking, people with Parkinson's disease maintain anticipatory control during object grasping. However, common functional tasks often include carrying an object while changing step patterns mid-path and maneuvering over obstacles, increasing task complexity and attentional demands. Thus, the present study investigated the effect of Parkinson's disease on the modulation of grasping force changes as a function of gait-related inertial forces. Subjects with Parkinson's disease maintained the ability to scale and to couple over time their grip and inertial forces while walking at irregular step lengths, but were unable to maintain the temporal coupling of grasping forces compared to controls during obstacle crossing. We suggest that this deterioration in anticipatory control is associated with the increased demands of task complexity and attention during obstacle crossing.

Introduction

People with Parkinson's disease (PD) often have difficulty with daily tasks requiring hand and finger dexterity. However, studies on precision grip report that most aspects of fingertip force coordination are unaffected by PD [10,14]. Many routine tasks require grasping while walking, involving the whole body and various levels of attention, such as shopping (e.g., handling money or groceries while walking) [22]. Therefore, these additional influences of transporting an object may underlie functional grasping deficits in PD.

When walking with a hand-held object, one must coordinate hand control with locomotion so as not to lose balance, trip or drop the object. As such, movements of the whole body related to gait cycle events generate inertial force (IF) changes acting on the object through the grasping arm [11,12]. Changes in grip force (GF) are closely coupled in time with IF changes to maintain the ratio of GF/IF when the regular or irregular gait pattern is predictable in healthy young and older adults [8,12]. Subjects with PD also maintain such anticipatory grasp control during simple unperturbed walking, tightly coupling the fingertip forces [1]. This occurs despite elevated GF/IF ratios indicating less efficient scaling of GF relative to controls. However, the complexity in the environment and/or step regularity is often altered in daily tasks, such as crossing obstacles or changing step length. In older adults anticipatory grasp control deteriorates during the complex and attention demanding task of stepping over an obstacle, but not during step length changes altering the regularity of gait-related IF fluctuations [8].

PD impacts the ability to perform concurrent tasks and coordinate several body segments simultaneously such as when stepping over obstacles [25] and walking carrying a tray of glasses or transferring coins [5,16]. Such tasks are thought to have an increased level of complexity related to multi-segment control [25], and to the attentional demands of performing simultaneous tasks [5,16]. Basal ganglia pathways have been associated with planning temporal and spatial aspects of multi-segment movements [19,24] and in executive functions, such as shifting and dividing attention [28]. Increased demands of task complexity and attention could therefore deteriorate grasp control of individuals with PD carrying an object while walking over an obstacle.

This study assessed the effects of task complexity and attentional demands (obstacle crossing) and gait regularity (step length changes) on anticipatory grasp control during object transport while walking in participants with PD. We altered subjects' stepping patterns and complexity by asking them to change, mid-path, their step length and to step over an obstacle, respectively, and examined the modulation of grasping forces and gait parameters related to the gait-induced IFs. We hypothesized that the PD-related impairment in performing complex movements and in

Abbreviations: PD, Parkinson's disease; grip GF, force; IF, inertial force; HC, heel contact; SMA, supplementary motor area.

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attention would result in a decline in temporal coupling of GF and IF during obstacle crossing. Based on findings in healthy elderly [8], we also hypothesized that participants with PD would maintain anticipatory control of grasp to changes in gait regularity per se (step length changes).

Materials and methods

Subjects

Nine individuals with idiopathic PD and 9 healthy age-matched controls participated in this study. All subjects were part of an earlier study on grasp control during gait [1]. The subjects were right-handed and for subjects with PD, bilaterally affected [Hoehn & Yahr >1]; ambulatory without assistive device, no orthopedic, psychiatric or neurological conditions other than PD; mini-mental state exam score ≥25; and fingertip sensation ≤5 mm on 2-point discrimination. Data were collected while PD subjects were "off" medication (12 h from last antiparkinsonian medication). All subjects gave informed consent. Protocols were approved by the Teachers College Columbia University Institutional Review Board.

Experimental setup

Grasp forces normal to the grasp surface (GF), vertical load forces and anterior-posterior horizontal forces tangential to the grasp surface were measured with transducers attached to a 300 g object (ATI Industrial Automation, NC). Kinematic data were recorded using an eight-camera 3D optical motion capture system (VICON, Oxford Metrics) with 39 markers (Plug-in-Gait model) and an additional marker on the grip device as subjects walked an 8.9 m path [1].

Protocol

For all conditions the subjects were instructed to hold the object between their right thumb and index finger and to maintain its position at approximately elbow level. Subjects were then asked to walk continuously at self-selected cadence and speed, looking straight ahead, and step alternately on visual cues of tape lines (5 cm × 100 cm) spaced apart at 40% of subject's height [23] throughout the 8.9 m straight path (*Baseline* condition). To implement the gait manipulations embedded within continuous walking, three additional conditions at self-selected speeds and counterbalanced across subjects, were subsequently performed in which line placements were individually adjusted on the middle step for each condition as follows. To evoke sudden gait deceleration and acceleration, subjects transported the object in one condition while taking one shorter step (33% of their baseline step length; *Short step*) mid-path and in another condition while taking one longer step (150% of their baseline step length; *Long step*) mid-path [8,12]. During the *Obstacle* condition, subjects stepped with their left foot leading over a 20 cm high horizontal bar placed mid-path [25], a similar height to typical stair-risers and parking lot curbstones where frequent tripping falls occur [7]. Subjects performed one practice trial and 5 trials were then recorded for each condition.

Data analysis

Fingertip forces and kinematic data were synchronized and sampled at 400 Hz and 120 Hz, respectively, and low-pass filtered at 6 Hz cut-off, selected to attenuate any action tremor and bias from the anti-phase nature of grip and load force oscillations [9]. The load and horizontal forces of the thumb and index finger acting on the object were combined [11] to obtain the IF. To examine the overall relationship of the GF and IF coupling during unperturbed walking conditions, cross-correlation r values and corresponding time lag (ms) were calculated between the force rates (dGF/t and dIF/t) using a ±12.5 ms window over the analyzed steps [11]. For statistical analysis the r values of the cross-correlations were transformed using Fisher's Z transformation. To more closely determine the influence of the altered step on grasp force coupling, time lags between peak GF (average of the thumb and index finger normal forces) and peak IF associated with heel contact were calculated. Positive values indicate GF lagged IF. The GF/IF ratio indicates efficiency of GF at maximum IF, typically occurring near heel contact [1,11,12]. To ensure steady-state gait velocity had been achieved, the three middle steps of each trial were analyzed, including the altered step, one step before and one after (Step −1, A, +1). A step was defined as the heel contact (HC) from one foot to the next, thus HC −2, −1, A and +1 delineated the analyzed steps. Gait velocity was calculated as the distance between HCs divided by step duration. Cross-correlations with time lags of force rates were obtained across all analyzed steps. Grasp measures (GF, IF, force ratios and peak-to-peak time lags) were determined for each of the four related HCs. To explore the relationship between gait velocity and IF, an object/C7 (trunk at base of neck) ratio of vertical peak-to-peak displacements was calculated [1].

To initially evaluate the overall effect of PD on phase measures (i.e., the period from HC −2 to +1) of grasp control (cross-correlation coefficient and corresponding time lags) univariate analysis was performed. To examine the effects of PD and alterations in step regularity in more detail, two separate ANOVAs with repeated measures on the factors of condition and heel contact or step were used. Firstly, analysis of point measures of grasp (GF, IF, force ratios and peak-to-peak time lags) used a group (controls, PD) by condition *(Baseline*, *Short step*, *Long step*) by heel contact (*HC* −2, −1, *A*, +1) ANOVA. Secondly, analysis of gait velocity used a two group by three condition by three step (*Step* −1, *A*, +1) ANOVA. To assess the effects of PD and demands of task complexity as subjects approached and crossed the obstacle, the same measures were submitted to a two group by four heel contact (for grasp measures) or three step (for velocity) ANOVA with repeated measures on HC or step. Measures are reported as means ± standard error. Statistical significance was set at $p < 0.05$. Newman–Keuls post hoc comparisons were performed where appropriate. Effect sizes are reported as partial eta squared (ηp^2).

Results

Gait parameters

Subjects with PD walked significantly slower than controls during baseline walking, but at similar velocities during the altered gait conditions (Table 1). All subjects significantly decreased gait velocity when taking short steps, during and one step after crossing the obstacle (Table 1). Likewise, subjects increased velocity during the long step, confirming that the imposed perturbations elicited significantly different step patterns.

Temporal coupling of fingertip forces

Anticipatory control of grasp, assessed by the extent of temporal coupling of fingertip forces, was first examined during unperturbed walking with cross-correlation analysis, showing similar r values and associated time lags for all subjects (PD: $r = 0.79 \pm 0.08$, -10 ± 3 ms; Controls: $r = 0.81 \pm 0.08$, -5 ± 5 ms; $p > 0.05$). Grasp force coupling associated with individual steps (i.e. peak-to-peak lags) was subsequently assessed for effects of gait regularity (step-length changes) and task complexity (obstacle crossing), separately. During *Baseline*, *Short* and *Long step* the time