Disruptive influences of a cued voluntary shift on coordinated movement in Parkinson’s disease

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Abstract

A temporary and/or involuntary stoppage of movement is identifiable in the execution phase of writing, walking, and turning movements in individuals with Parkinson’s disease (PD) and may be referred to as freezing. However, the unpredictability of such akinetic impairments has made it difficult to study experimentally. The present study compared PD and age-matched control groups in their ability to coordinate continuous and simultaneous upper limb movements in trials involving two parts. In the first part of each trial, participants performed either in-phase movements (symmetric, simultaneous movement toward and away from the midline of the body), or anti-phase movements (isodirectional). At the midpoint of the trial, they were signaled by an auditory metronome to execute an intentional and voluntarily switch from the coordination currently being performed to the opposite coordination pattern. In the second half of the trial participants were required to maintain performance in the other coordination mode. All trials were paced by an auditory metronome at one of three different speeds (0.75, 1.25, 1.75 Hz). Measures of temporal coordination (relative phase) indicated that overall, participants with PD required significantly longer periods of time to achieve a switch between coordination patterns compared to healthy controls, and experienced greater difficulty changing from the in-phase to anti-phase mode of coordination. As well, movement stoppage was observed in 53.9% of the in-phase to anti-phase switch trials, but in only 15.5% of the anti-phase to in-phase trials. We conclude that interruptions to movement execution are most common when switching to coordinated movements that impose greater motor demands in individuals with PD.

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Keywords: Bimanual coordination; Freezing; Intentional shift; Parkinson’s disease; Attention

1. Introduction

Individuals with Parkinson’s disease (PD) experience difficulty in the execution of sequential and simultaneous movements. Severe impairments such as freezing are clinically described as a temporary inability to produce voluntary movement [1] and are of particular interest because of their implications for independent living. Although freezing is often considered a problem that occurs at the initiation of movement, retrospective clinical evaluations by Giladi et al. [2,32] have also described freezing-associated impairments that occur during movement execution. In addition to the common initiation problems associated with speaking, writing and sit-to-stand, their study reviewed execution impairments in activities that seem to require an attentional shift, resulting in hesitation and even abortion of movement during the on-line challenge of switching between movement tasks. Examples included the gait switch from the final step of ascending a staircase to normal gait on a flat surface; maintenance of gait to enter an elevator when the door suddenly begins to close; continuing gait over a change in floor texture; and switching from forward to sideways locomotion. It is also important to note that these disruptions to movement are not limited to the lower limbs. Early experimental research conducted by Schwab et al. [3] found that individuals with PD displayed amplitude, speed, and accuracy deficits when required to coordinate two simultaneous tasks between hands. Examples included the gait switch from the final step of ascending a staircase to normal gait on a flat surface; maintenance of gait to enter an elevator when the door suddenly begins to close; continuing gait over a change in floor texture; and switching from forward to sideways locomotion. It is also important to note that these disruptions to movement are not limited to the lower limbs. Early experimental research conducted by Schwab et al. [3] found that individuals with PD displayed amplitude, speed, and accuracy deficits when required to coordinate two simultaneous tasks between hands. When required to squeeze an ergogram bulb with one hand and simultaneously connect points on a triangle with the other, some participants would completely cease one task before completing the other. One common explanation for this inability to maintain simultaneous upper limb movements is that individuals with PD are unable to separate plans of action for each limb, which may be related to an attention-shifting deficit when transferring between different motor tasks [3–6]. Recent studies have
documented an interruption-to-movement impairment during the execution of complex movements. In tasks involving several movement segments, individuals with PD display a marked delay between the execution of each sequential movement segment, particularly when the segments involved different actions [7,8]. Curra et al. [9] made similar observations using a sequential line drawing task. Their results showed that individuals with PD encountered movement disruption when required to complete a full movement sequence to produce a drawing. In contrast, a step-wise cueing of each segment of the same drawing allowed individuals with PD to perform with the accuracy and speed of healthy controls. They concluded that deficits in movement execution occur in situations where individuals with PD are required to process a greater quantity of information per unit of time. The results of such studies support the notion that individuals with PD have difficulty shifting attention in order to perform on-line modification of motor steps during the execution of a complex movement [3,10,11].

The present study of interlimb coordination provides a unique examination of attention demands during an on-line voluntary switching between stable but complex movement patterns. Bimanual movements that involve simultaneous limb actions toward and away from the midline of the body are termed in-phase, while movements involving both limbs moving synchronously to the left or right are termed anti-phase. Both patterns have been studied in healthy populations and are considered automatic because of the accuracy and consistency across a wide range of situations and because they can be performed optimally without the need for practice [12,13]. Of these two patterns, the attraction to in-phase movements is so powerful that both young and older adults spontaneously switch to in-phase coordination when asked to perform other coordinated movements, such as anti-phase movements, at a faster movement speed [14]. Older adults, when compared to young adults however, required a greater amount of time when switching out of the in-phase mode of coordination, as compared to switching out of anti-phase coordination.

Examinations of individuals with PD reveal that deficits observed in sequential and simultaneous limb movements are more apparent in the anti-phase pattern which involves simultaneous contraction of opposite muscle groups, than in-phase modes of coordination (simultaneous symmetric contraction of homologous muscle groups), and that this may be associated with the demands of spatio-temporal coupling of the limbs [15–18]. In fact, recent bimanual research has speculated about the demands of information processing during PD coordination, and have demonstrated that increasing task difficulty can lead to impaired frequency and amplitude of movement, as well as spontaneous shifts [19–22] or abortion of coordinated movement [21]. In a previous experiment we replicated these observations and also found that impairment of anti-phase coordination was evident in the form of hypometric and stoppage of movement deficits [23]. These interruptions to movement are a particularly disabling complication in PD since the problem is resistant to treatment with anti-Parkinsonian agents and is commonly observed while patients are taking their prescribed medications (as observed in our recent study).

The objective of the current study was to determine whether a cued intentional shift during the execution of the more stable in-phase movement pattern to the less stable anti-phase pattern (and vice versa) would influence movement execution in individuals with PD (compared to healthy, age-matched controls). To increase demands on the motor system, these voluntary switch trials were performed at three different movement frequencies (0.75, 1.25, 1.75 Hz), as paced by an external timing signal. Specifically, our aim was to establish if interruptions to movement, would be more apparent in participants with PD when the task demanded a switch from a more automatic to less automatically coordinated movement.

2. Method

2.1. Participants

Thirteen participants (participating in an out-patient exercise rehabilitation program) with idiopathic PD (average age 68.1 years, range 58–82 years), and 13 gender-matched and age-matched healthy controls recruited from the community (aged 67.9 years, range 52–81 years) consented to participate in the experiment. Ethics approval for testing was received by the Board of Ethics at St. Peter’s Hospital, Hamilton, Canada. All participants with PD were evaluated at the same time of day, 2 h after having taken their morning or afternoon medications, while maintaining their regular medication protocol. 2 h post-medication was felt to be a time of optimal “on” effect of medication, since this was the time that they were best able to participate in the exercise program. Each individual with PD completed selected sections of two batteries: (a) the motor examination section of the Unified Parkinson’s Disease Rating Scale (UPDRS) [24], which measured upper limb PD symptoms, and (b) the modified Hoehn and Yahr scale [25].

Descriptive characteristics of participants with PD are presented in Table 1. Individuals were included if they were scored as stage I, II or III on the Hoehn and Yahr scale. All participants were assessed for working memory capacity using the Digit Span Test [26] and screened for dementia using the Mini-Mental State Examination [27] to verify that they were within the range of their age-expected norms (minimum score of 23 out of 30 was required). Participants were self-declared as right hand dominant, with normal-to-corrected vision in both eyes, and were free of shoulder injuries, neurological deficits or other movement complications (such as dystonia or dyskinesia as confirmed by subsections 31–35 of the UPDRS) that might influence their ability to complete the required movements.
and the second half in the opposite mode (see Fig. 1). The trial would be performed in one coordination mode to produce an ‘X-like’ trace on the monitor, since the first half movement produced the opposite diagonal (bottom right of the computer screen) and the second half followed the abscissa, while the left arm displacement moved the corresponding output signal (Lafayette Instrument Co.).

2.2. Apparatus

Participants were seated comfortably such that their fore-arms were parallel to a table-mounted sliding mechanism. The sliding devices consisted of two 9 cm × 13 cm metal carriages, with an 8 cm plastic molded hand-grip bolted vertically to the surface of each carriage. The carriages were attached with low-friction, ball bearing rollers to a metal track, which restricted motion to a linear plane. Two clearly defined and symmetrical 16 cm regions, marked on the base of the apparatus (one for each limb) served as visual cues for the amplitude boundaries of the required movements. Linear potentiometers (BEI Electronics Company) were attached in parallel to the sliding device to encode displacement.

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2.3. Procedure

Participants were instructed to continuously coordinate simultaneous displacements of the two linear sliding devices in either the in-phase or anti-phase pattern, at a pace determined by the external auditory device. For in-phase movements, participants moved both limbs simultaneously toward and away from the midline of the body, whereas anti-phase required the movement of both limbs to the right and left simultaneously (Fig. 2). In each 20 s trial, a full cycle of movement (which would return a participant’s limbs to their starting point) was to be performed for each auditory tone emitted, using the 16 cm marked amplitude region on the sliding device as guides for the appropriate movement amplitude to be produced. Participants were given a description of the typical trace that would result from their limb movements, and encouraged to use it as a source of feedback although they were not required to focus on the visual display at all times.

A total of 18 trials were administered. Nine of these trials started with the in-phase movements and the other nine trials started with the anti-phase pattern. Each trial for a given phase was 20 s in length and progressed in order from slowest to fastest (0.75, 1.25 and 1.75 Hz) before a new block of three trials began. Blocks of in-phase or anti-phase trials were run in a counterbalanced order. Participants were instructed that a louder and higher pitched tone (the auditory switch cue) would sound halfway (10 s) into the trial, at which time they were to switch from the coordination pattern from which they started to the other coordination pattern (i.e. from in-phase to anti-phase or from anti-phase to in-phase). Participants were instructed to make the appropriate phase shift as soon as they heard the auditory stimulus and to maintain the new pattern with the appropriate timing until the end of the trial. Participants were verbally reminded which pattern they would start with, and would switch into, after every block of three trials. Before the
experiment started, participants were provided with up to five practice attempts at switching between phases without any external timing signals, to verify task comprehension. Participants were also instructed that it was very important to move continuously (without stopping) during the entire 20 s trial.

2.4. Data analysis

Data were calibrated to the real amplitude of movement in engineering units, and then processed through a Butterworth (low-pass filter) at 10 Hz using the DADiSP Software program. The final 10 s of each trial was extracted and saved in
an interactive window for analysis. Within each extraction, the portion of the waveform in which a successful switch (as defined later) to the intended coordination pattern was accomplished was further isolated into a second window for analysis of timing performance.

Relative phasing of the limbs was quantified by a continuous and instantaneous estimate of the position of the left limb with respect to the right limb, using the formula presented by Kelso [29]:

\[
\theta = \tan^{-1}\left( \frac{\Delta X_g/dt}{X_R} \right)
\]

where \( \theta \) is the relative phase between limbs at each sample, \( X \) the positions of the limb within a cycle rescaled to the magnitude \([-1, 1]\), \( dX_g/dt \) refers to the continuous, normalized instantaneous velocity. The sum of these relative phase angles divided by the number estimates provided a measure of average relative phase for each analyzed segment. Accuracy of relative phasing performance between the limbs was subsequently calculated as the absolute difference between the average relative phase and the relative phase of the intended pattern where in-phase was quantified by a relative phase of 0° and anti-phase was represented by 180° relative phase. Within-trial standard deviation provided a measure of stability for the segment of trial that met criterion. These measures are standard dependent measures for analysis of temporal coordination (e.g. [13,23,29]).

A successful switch to a new phase was defined using more stringent criteria than those established by previous researchers [14–30]. A switch was defined, according to our previous work [35], as achievement and maintenance of the intended coordination mode within 45° of relative phase for a minimum duration of 2 s. The dependent measure characterizing the time required to achieve a new mode of coordination was labeled ‘voluntary switch time’. Voluntary switch time was quantified as the latency between presentation of the auditory switch cue and the start of the 2 s bandwidth that successfully achieved the switch criteria (i.e. within 45° relative phase of the intended goal pattern for a minimum of 2 s).

In order to characterize deficits that occurred during the voluntary switch time interval, we calculated the percentage of trials in which freezing (as defined later) and/or other movement interruptions occurred (Table 2). In the present study, periods of freezing were defined as the ‘temporary inability to execute voluntary movement’ [2,32]. Empirically, freezing was defined strictly as any period of at least 1 s in which one, or both of the limbs displayed no movement (as reflected by a zero change in amplitude). Further, a ‘delayed response’ to the auditory switch cue was delineated by a voluntary switch time that was longer than 2 s before a change in amplitude was observed.

Data were analyzed statistically using a three-factor mixed ANOVA, in which group was the only between-participant variable. The design was a group (Parkinson’s, control) × phase (in-phase, anti-phase) × speed (0.75, 1.25, 1.75 Hz). All significant interactions were subjected to Tukey’s HSD post hoc analyses.

3. Results

3.1. Examples of coordination performance

Fig. 3 displays representative (a) in-phase and (b) anti-phase trials from a control subject, as well as (c) freezing and (d) delayed response interruptions experienced by participants with PD. Table 2 summarizes the frequency and percentage of trials in which these deficits occurred in individuals with PD. These types of movement impairments were not observed during any of the trials performed by healthy controls. It should also be noted that the possibility of these disturbances being dystonic or dyskinetic is very unlikely, as there were no observable abnormal postures or choreiform movements noted during movement disruption episodes. Of all trials in which participants with PD were asked to switch from the in-phase to the anti-phase pattern, freezing was experienced in 11.1% for the right hand, 12.9% for the left hand, and 29.9% involving both hands (total = 52.9%). Also, 3.4% of ‘switch to anti-phase’ trials were categorized as delayed response, while in 7.6% of trials a successful switch was never accomplished (i.e. the participant would have continued in the initial pattern to the end of the trial). In total, some form of empirically defined impairment occurred in over 64% of these trials for individuals with PD. In contrast, when participants with PD were required to switch to the in-phase pattern, freezing was observed in only 3.4% of the right hand, 4.3% of the left hand, and 7.8% of trials involving both hands. Comparatively, there were no trials in which participants were unable to successfully switch to in-phase, and only 1.7% of trials resulted in delayed response (total < 20%). Overall, these results indicate that switching from the in-phase to the anti-phase coordination pattern was strongly associated with much

Table 2

<table>
<thead>
<tr>
<th>Movement impairment trials in participants with Parkinson’s disease</th>
<th>Freezing—right hand</th>
<th>Freezing—left hand</th>
<th>Freezing—both hands</th>
<th>Delayed response</th>
<th>No switch achieved</th>
<th>Total freezing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anti- to in-switch</td>
<td>4 (3.4%)</td>
<td>5 (4.3%)</td>
<td>9 (7.8%)</td>
<td>2 (1.7%)</td>
<td>0 (0%)</td>
<td>18 (15.4%)</td>
</tr>
<tr>
<td>In- to anti-switch</td>
<td>13 (11.1%)</td>
<td>15 (12.9%)</td>
<td>35 (29.9%)</td>
<td>4 (3.4%)</td>
<td>9 (7.6%)</td>
<td>63 (53.8%)</td>
</tr>
</tbody>
</table>

Percentage of trials is based on the total number of trials in a specific coordination mode performed by all PD patients (117 trials).
3.2. Relative phase

Performance accuracy, as represented by absolute mean error of relative phase, is illustrated in Fig. 4 for the trials in which a successful switch was accomplished. The figure shows that the PD group performed as well as controls when transferring to the in-phase mode of coordination. However, participants with PD, unlike controls, exhibited decrements to accuracy after switching to the anti-phase mode. These findings were substantiated by significant main effects for group $F(1, 24) = 9.73, P < 0.01$, and phase $F(1, 24) = 18.70, P < 0.001$, as well as a group X phase interaction, $F(1, 24) = 7.31, P < 0.01$. Post hoc results indicate that the control group performed accurately regardless of the coordination mode to which they were required to switch. In addition, a three-way interaction for group, phase, and speed, $F(2, 48) = 3.71, P < 0.05$, was also significant, indicating that both groups were able to switch accurately to the in-phase pattern regardless of movement speed requirements. However, switches to the anti-phase pattern were performed with poorer accuracy across all speed conditions for the group with PD (Fig. 5). Post hoc analyses confirmed that participants in the control group transferred to the anti-phase mode as accurately as they switched to the in-phase mode across all movement speeds except the fastest (1.75 Hz) condition, where switching to the anti-phase pattern was significantly less accurate. Interestingly, participants with PD displayed greater accuracy deficits when transferring from in-phase to anti-phase at the slowest and fastest movement speeds (0.75 and 1.75 Hz, respectively), when compared to the moderate speed (1.25 Hz) condition.

Fig. 6 illustrates the finding that all participants were more variable (as reflected by standard deviation) when switching to the anti-phase, compared to the in-phase coordination pattern. This variability was most evident in the PD group.
and confirmed by main effects for group, $F(1, 24) = 16.15, P < 0.001$, phase, $F(1, 24) = 53.78, P < 0.00001$ and a significant two-way interaction between group and phase, $F(1, 24) = 11.00, P < 0.01$. Post hoc results further revealed that all participants were equally stable when switching to in-phase coordination, while participants with PD were significantly more variable than controls in switching to the anti-phase task. A main effect for speed, $F(2, 48) = 4.06, P < 0.05$ was also found, indicating that there was an overall loss of stability associated with the slowest and fastest movement speeds. Post hoc results indicate that a similar loss of stability was associated with both the slowest and fastest movement speeds, while improvements were evident at the intermediate speed condition.
3.3. Voluntary switch time

The difficulty in switching from the in-phase to the anti-phase pattern was also confirmed by ‘voluntary switch time’ as a dependent measure (Fig. 7). The individuals with PD required a substantially longer time to change to the anti-phase mode of coordination when compared with switching to the in-phase mode, and when compared to the controls performing the same switch task. In fact, post hoc results indicate that participants with PD required no more time than controls to switch from the anti-phase to the in-phase coordination mode. This was confirmed by a main effect for group, \( F(1, 24) = 11.38, P < 0.01 \), and phase, \( F(1, 24) = 17.84, P < 0.001 \) as well as a significant two-way interaction between group and phase, \( F(1, 24) = 6.44, P < 0.05 \).
4. Discussion

A movement interruption impairment associated with PD that typically occurs at the initiation of movement is termed freezing. The current experiment has shown that disruption to movement and/or freezing can also be identified during the execution of continuous movements. Freezing during the execution of movement has been identified recently as an important clinical issue [31] and was the primary focus of this study. Previous studies have provided evidence of movement execution impairments when individuals with PD divide attention and separate plans of action involving different movement sequences [2–7]. As confirmed by and explored in the present study, interruptions to normal movement are apparent when sequences involve simultaneous coordination of both limbs [1,4,15,21].

The present study integrated a continuous bimanual coordination task with the intentional requirement of changing between coordination patterns midway through a trial. Previous research predicts that coordination of anti-phase movements should be more difficult for individuals with PD [15,16,19–21]. An earlier study in our lab confirmed this hypothesis for continuous bimanual coordination tasks, and determined that difficulties in the execution of anti-phase movements were accompanied by spontaneous bouts of movement interruption and hypometric deficits occurring in 8.1 and 5.1% of anti-phase trials, respectively [23]. It was postulated that difficulties observed in anti-phase coordination for individuals with PD might be due to the demands of inhibiting limb synchronization (i.e. in-phase coordination). Although anti-phase movements share a common timing element (similar to in-phase movements), these movements are not mirrored and hence are not as spatio-temporally linked as in-phase movements [14]. The compounded effect of external pacing and the requirement of an intentional switch during movement is a complex relationship, and one that we propose is not simply related to an increase in motor demand. If this were the case, we would have predicted an increase in absolute error (and greater disruption to movement) for each increase in speed of the required movement. This however was not observed. In fact, both the slowest and fastest paced movements were performed with more error.

To suggest a neural mechanism for our findings, we refer to the original (1964) notion of “motor set” published in Neuropsychologia by Talland and Schwab [6]. They described a central programming deficit in Parkinsonian populations, such that multiple motor sets (i.e. tasks that involve more than one simple movement, or simultaneous movements) are not well maintained. More recent research has also proposed that different mechanisms may be responsible for motor set shifting, depending on whether the cue is external or internal [40]. From this perspective, in-phase and anti-phase movements may be considered motor sets that require maintenance as they are repeated continuously. Experimental evidence supports the involvement of higher cortical centers such as the supplementary motor (SMA) and premotor areas (PM) in the control of bimanual movements [16,36]. Although the specific mechanism for existence of “motor sets” requires further research, it is probable that in their projections to the neostriatum the SMA internally guides the coordinative aspects of the bimanual motor set, while the premotor cortex monitors the timing dictated by an external pacing signal. Thus, cortical projections to the basal ganglia could (via the thalamus) provide neural feedback to primary motor areas for maintenance of a motor set.

Cognitive influences of attention on preferred modes of coordination have also been studied [23,33,34], as well as the prefrontal neuronaunatomical correlates for movements that are controlled through automatic processes [35–37]. These studies support the involvement of associative cortical areas (i.e. dorsolateral prefrontal cortex) that project both through the SMA (to the neostriatum) and directly to the neostriatum for intentional modulation of a motor set. As maintenance of the motor set becomes more automatic, research has demonstrated a decrease in activation of these dorsolateral prefrontal neurons [36]. In a recent experiment, Brown and Jahanshahi [41] demonstrated that as a bimanual motor set becomes more automatic, it may even enhance motor performance. This would be probable since there would be less interference from the prefrontal cortex. Further, it has been suggested that attentional mechanisms may be more reflexive in individuals with PD [42], which may relate to atypical processing through the basal ganglia. It is proposed then, that the prefrontal cortex may impose control over a motor set during slower speeds (since more attention can be focused on precisely achieving a coordinated task) and faster speeds (when more cognitive effort is required to maintain a coordinated task), and that this may lead to movement difficulties.

The use of an intentional switch task further tests this motor set hypothesis, since responding to a switch cue requires intentional control (and hypothesized prefrontal activation) to initiate a new motor set [14,33–35,38]. If this were the case, then we would expect greater deterioration and interruptions of movement if switching to the anti-phase motor set were attempted intentionally during the course of a trial. Further, since our previous research with externally paced speed increments demonstrated traces of freezing and motor disturbance, we hypothesized that the combined demand imposed by an external pacing component, in addition to the internal cognitive demand of switching between motor sets, would present a further attention challenge (i.e. greater prefrontal contribution to movement control) in order to disentangle the differences between in-phase and anti-phase coordination.

In our study, switching to an in-phase mode of coordination was achieved no differently for individuals with PD than by healthy controls. Difficulties in coordinating movements were reflected in the poor accuracy and stability achieved by individuals with PD in switching to the anti-phase mode of coordination. Furthermore, similar to controls, accuracy and stability results showed that participants with PD were not influenced by speed requirements after switching to the
in-phase pattern. Yet they were profoundly influenced by speed when required to switch to the anti-phase coordination task. Our results indicate that there may be an optimum speed at which individuals with PD can achieve an accurate and stable state for coordination.

Our findings for the control group support previous research examining intentional switches between in-phase and anti-phase movements which suggests that the strong attraction for the in-phase mode of coordination acts to constrain intentional modifications to movement coordination [33], and further reaffirms this hypothesis for individuals with PD [19,34]. Healthy young and older adult populations also require more time when transferring from in-phase to anti-phase modes of coordination (compared with anti-phase to in-phase shifts), which is thought to be due to a greater attraction for symmetrical in-phase movements [17,33]. Our research indicates that these constraints are exacerbated in individuals with PD. Intentional switching to the anti-phase task required more than double (2.65 s) the amount of time that healthy, older adults needed to achieve the same switch (1.11 s). Yet, participants with PD required no more time than controls when switching to the in-phase movement pattern. This suggests that the general coordination tendencies of individuals with PD are constrained by in-phase modes of coordination more so than in healthy older adults. Further, our results support the notion that more difficulty is associated with intentionally destabilizing in-phase rather than anti-phase movements since the in-phase coordination mode is intrinsically more stable [14].

Difficulties in processing a voluntary switch within a movement task is perhaps most evident in the percentage of trials in which specific movement disruptions occurred for individuals with PD. Participants with PD were unsuccessful in changing to the anti-phase mode at all in 7.6% of the trials. This, in itself could be considered a form of freezing or failure to initiate the appropriate movement. Remarkably, more than half of the trials (53.8%) requiring a switch from in-phase to the anti-phase pattern resulted in a transient episode of movement interruption or ‘freezing’ (for at least one full second). Although infrequent and unrelated to side affected by disease, this ‘freezing’ occurred occasionally in just one of the limbs (24%). The limbs seemed to become dissociated in these situations, and it appeared as though participants would sacrifice control of one limb so that they were able to at least maintain movement in the other limb. Further, in 3.4% of the trials requiring a switch to the anti-phase pattern, participants with PD exhibited a delay greater than two-seconds in responding to the switch signal. Although some of these observations did occur when switching to the in-phase task, the frequency of occurrences was less than a third of the observations made when switching to the anti-phase task. These findings are consistent with a proposed cognitive influence over motor set, and provide evidence that individuals with Parkinson’s disease may have difficulty maintaining and switching between motor sets. This may be a possible mechanism for freezing, and is supported by recent research investigating the influence of attentional cues on gait modulation [39].

Overall, the use of a continuous bimanual coordination task may serve as a useful paradigm through which to identify sudden episodes of freezing associated with on-line changes in the execution of continuous upper limb movements. Our results suggest that disruptions to normal movement are more likely to occur when switching to movements that involve anti-phase coordination. PD difficulties switching from in-phase to the anti-phase coordination mode were evident in all dependent measures (accuracy, stability, and voluntary switch time), although they were not present during intentional switches in the opposite direction. The results of this experiment suggest that short episodes of freezing occur during execution of coordinated simultaneous movements that involve on-line changes away from relatively stable movement patterns, in addition to previously identified problems at the initiation of movement. Further experimentation is required to determine whether initiation and execution deficits, such as freezing are a result of the same underlying mechanisms.

Acknowledgements

The research presented here reflects part of the requirements for the Master’s degree in Human Biodynamics, awarded to the first author from McMaster University. We gratefully acknowledge the assistance of the staff and patients of Dr. Peter’s Hospital in Hamilton, Ont., Canada for their contributions to this research. Also, we acknowledge the support provided by the Ontario Ministry of Health and by Michele Shilton and John Moroz. Correspondence should be addressed to Quincy Almeida, Movement Disorders Clinic, Room 10-L9A, London Health Sciences Centre, University Campus (e-mail: qalmeida@uwo.ca).

References


