Bimanual co-ordination in Parkinson’s disease

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Summary
The basal ganglia may be involved in bimanual co-ordination. Parkinson’s disease (which impairs basal ganglia output) is clinically reported to cause difficulties in the performance of co-ordinated bimanual movements. Nevertheless, any bimanual co-ordination difficulties may be task specific, as experimental observations are equivocal. To infer the role of the basal ganglia in co-ordinating the two arms, this study investigated the bimanual co-ordination of patients with Parkinson’s disease. Sixteen Parkinson’s disease patients and matched control subjects performed a bimanual cranking task, at different speeds (1 and 2 Hz) and phase relationships.

Keywords: bimanual co-ordination, basal ganglia, Parkinson’s disease

Abbreviation: SMA = supplementary motor area

Introduction
Aspects of basal ganglia function may be investigated by examining the ability of Parkinson’s disease patients to perform simultaneous bimanual tasks. Parkinson’s disease is associated with dysfunction of the nigrostriatal system and the basal ganglia generally (Marsden, 1990). Clinical observations suggest that such patients have difficulty in co-ordinating their upper limbs in both simultaneous and sequential movement tasks; however, the experimental evidence is equivocal.

Bimanual co-ordination requires internal sequential control to mediate the integrated performance of the two hands. Where the two hands perform identical, mirror-symmetrical movements involving homologous muscle systems, a common programming element may be involved in their direction (Stelmach and Worringham, 1988). A mirror-symmetrical task is usually relatively easy to perform since the timing of the two hands is identical. An example is the bimanual in-phase task, where both hands perform cyclical movements, the right hand moving in a clockwise direction, and the left hand moving in an anticlockwise direction.

All subjects performed the required bimanual in-phase movement on a pair of cranks, at fast (2 Hz) and slow (1 Hz) speeds. However, the Parkinson’s disease patients were unable to perform the asymmetrical anti-phase movement, in which rotation of the cranks differed by 180°, at either speed; but instead reverted to the in-phase symmetrical movement. For Parkinson’s disease patients, performance of the in-phase movement was more accurate and stable when an external timing cue was used; however, for anti-phase movement, the external cue accentuated the tendency for patients to revert to more symmetrical, in-phase movements.

Alternatively, the hands may perform the same task, with the same timing, but at different points in the movement cycle, producing a more complex phase relationship. An example is the bimanual anti-phase task, where one hand is 180° out of phase with the other. The action is no longer mirror-symmetrical, and the homologous muscles are activated in sequence, rather than simultaneously, making it far more complex than the in-phase movements.

Of the few studies investigating the performance of Parkinson’s disease patients on bimanual tasks, most have found that these patients have a deficit in performing two manual operations either simultaneously or sequentially. These studies (Schwab et al., 1954; Talland and Schwab, 1964; Horne, 1973; Benecke et al., 1986, 1987; Shimizu et al., 1987; Horstink et al., 1990; Lazarus and Stelmach, 1992) used a different task for each hand, such as squeezing an object or tapping a pattern with one hand, and drawing triangles or transferring beads with the other. The difficulties shown by the Parkinson’s disease patients included slower movement times and longer pauses between movements,
compared with the control subjects. The patients preferred to perform one movement, pause, then perform the other, avoiding simultaneous, continual movements. Castiello and Bennett (1997) found subtle differences between Parkinson’s disease patients and control subjects in a bilateral reach and grasp movement, but found no differences overall between the two groups.

Three studies (Cohen 1970; Stelmach and Worringham, 1988; Brown et al., 1993), found no deficits in bimanual co-ordination by Parkinson’s disease patients, compared with control subjects, when they used the same task for each hand, performed simultaneously. These tasks included repetitive finger tapping and the Purdue Pegboard Task, where metal pegs were repetitively placed in a vertical row of holes (Brown et al., 1993), and discrete bimanual aiming movements (Stelmach and Worringham, 1988). Stelmach and Worringham (1988) found that all subjects needed more preparation time for the asymmetrical movements, and they executed asymmetrical bimanual movements more slowly than the symmetrical movements. When targets were placed at different distances for each hand (asymmetrical condition), both groups modified the actions of each hand so that they moved to the targets at the same time; that is, the movements tended to be organized as a single unit, moving in symmetry. With an anti-phase task of wrist flexion and extension, Cohen (1970) found that, like control subjects, the Parkinson’s disease patients tended to spontaneously drift from anti-phase pronation and supination of the wrist, to in-phase movement (symmetrical) which used homologous muscles. However, their study only used three Parkinson’s disease patients.

Verschueren et al., (1997) found that when an external visual cue was given to Parkinson’s disease patients who were performing a continuous bimanual flexion–extension movement with a 90° phase difference between the arms, they performed as well as the control subjects. When the cue was withdrawn the control subjects’ performances improved. However, the patients’ performance did not and they drifted towards the more stable in-phase and anti-phase movements. Parkinson’s disease performance is typically deficient in the absence of external cueing. This problem with internally generating movements may be offset by provision of extra external cueing. Thus patients may perform learned response sequences more easily with the provision of auditory (Georgiou et al., 1993; Kritikos et al., 1995) and visual (Jones et al., 1992; Georgiou et al., 1994; Martin et al., 1994; Jackson et al., 1995; Kritikos et al., 1995; Verschueren et al., 1997) cues, especially in terms of initiating and executing responses in a sequential task. Parkinson’s disease patients show marked impairment in rhythm generation in the absence of external cues (Freeman et al., 1993), and rely more on external feedback during movement performance (Flowers, 1976; Stern et al., 1983). They may also be deficient in simultaneous movements at faster speeds (Soliveri et al., 1992), and tend to tap rhythms too quickly at the lower (1–3 Hz) target frequencies, and too slowly at the higher (5 Hz) target frequency (Freeman et al., 1993). Parkinson’s disease patients may be deficient in performing complex, sequential movements (Rafal et al., 1987; Robertson and Flowers, 1990; Harrington and Haaland, 1991; Georgiou et al., 1993). Such movements of course typify bimanual co-ordination. Timing and rhythm reproduction have been found to be more variable in such patients (Nakamura et al., 1978; Pastor et al., 1992; Freeman et al., 1993) who also show deficits in automatic, overlearned responses with low attentional demands (Schwab et al., 1954), and where little reliance on or guidance from environmental input is necessary.

Inconsistent Parkinson’s disease findings may reflect the precise nature of the co-ordinative task. Most studies investigating normal bimanual co-ordination have found that anti-phase movements (where the movements involve the non-homologous muscles of both arms simultaneously, 180° out of phase) are not as stable nor as accurate as in-phase movements (where homologous muscles are active simultaneously and symmetrically) (Riek et al., 1992; Byblow et al., 1995; Carson, 1995; Summers et al., 1995; Swinnen et al., 1995). Indeed the anti-phase movement tends to revert to the in-phase movement, especially at faster speeds (Kelso et al., 1981; Kelso, 1984; Byblow et al., 1994, 1995; Lee et al., 1996).

This study therefore specifically investigated the possible function of the basal ganglia in the control of bimanual co-ordination, involving bimanual in-phase and anti-phase movements, and the nature of associated motor deficits in Parkinson’s disease. Half of the trials were performed with an external (metronome) cue, and the other half without an external cue. To better elicit any performance deficit, in-phase and anti-phase movements were performed at fast (2 Hz) and slow (1 Hz) speeds. Variability and accuracy of the movements and velocities were measured. It was predicted that the Parkinson’s disease patients would be less accurate and more variable in the speed and co-ordination of their movements.

Method

Subjects

Eleven male and five female patients with Parkinson’s disease were tested. They ranged in age from 48 to 78 years, with a mean age (± SD) of 62.5 ± 7.76 years. Parkinson’s disease patients were assessed immediately after the experimental testing on the Webster scale (Webster, 1968) to assess their symptoms; scores were in the range of 3–18 (mean 8.89 ± 4.5). There was no significant correlation between the Webster scores and the ages of the Parkinson’s disease patients, r(15) = –0.0884, P = 0.745. Their medication included l-dopa preparations (Sinemet, Madopar) and dopamine agonists (see Table 1). All of the patients were tested during the ‘on’ phase of their medication cycle. Control subjects were matched for age and sex; their ages ranged from 48–77 years, with a mean age of 62.5 ± 8.24 years.

All subjects were right-handed, as determined by a
Table 1 Clinical data for Parkinson’s disease patients

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Sex</th>
<th>Webster score</th>
<th>STMS</th>
<th>Duration of disease (years)</th>
<th>Medication</th>
<th>Side of disease onset</th>
</tr>
</thead>
<tbody>
<tr>
<td>53</td>
<td>M</td>
<td>4</td>
<td>36</td>
<td>18</td>
<td>Sinemet 600/150, Sinemet CR 1300/325, Tryptenine 1 mg, Permax 750 µg, Elderpryl 5 mg</td>
<td>Left</td>
</tr>
<tr>
<td>66</td>
<td>M</td>
<td>5</td>
<td>37</td>
<td>12</td>
<td>Sinemet CR 1800/450, Madopar 350/87.5, Sinemet CR 500/50, Madopar 150/37.5, Permax 750 µg</td>
<td>Unsure</td>
</tr>
<tr>
<td>66</td>
<td>M</td>
<td>3</td>
<td>34</td>
<td>12</td>
<td>Madopar 400/100, Risperidone 1 mg, Sinemet CR 500/50, Madopar 150/37.5, Permax 750 µg</td>
<td>Right</td>
</tr>
<tr>
<td>61</td>
<td>M</td>
<td>7</td>
<td>37</td>
<td>17</td>
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<td>Right</td>
</tr>
<tr>
<td>66</td>
<td>M</td>
<td>11</td>
<td>36</td>
<td>8</td>
<td>Liquid sinemet 70 mg, Sinemet CR 100/25, Sinemet CR 500/125, Permax 1125 mg, Madopar 800/200, Sinemet 50 mg</td>
<td>Right</td>
</tr>
<tr>
<td>69</td>
<td>M</td>
<td>14</td>
<td>33</td>
<td>30</td>
<td>Sinemet CR 500/125, Permax 1125 mg, Madopar 1000/250</td>
<td>Right</td>
</tr>
<tr>
<td>64</td>
<td>F</td>
<td>13</td>
<td>29</td>
<td>17</td>
<td>Madopar HBS 500/125, Madopar 1000/250, Sinemet CR 800/200, Eldepryl 10 mg</td>
<td>Right</td>
</tr>
<tr>
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<td>6</td>
<td>30</td>
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<td>F</td>
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<tr>
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<td>38</td>
<td>5</td>
<td>Madopar 600/150, Madopar HBS 200/50, Sinemet CR 1000/250, Permax 750 µg</td>
<td>Right</td>
</tr>
</tbody>
</table>

STMS = Short Test of Mental Status.

handedness questionnaire (Patterson and Bradshaw, 1975). Subjects were excluded if they were <40 or >80 years of age, or if they had a history of stroke, head injury or other neurological disturbance, suffered dementia [below 29 out of 37 on the Short Test of Mental Status (Kokmen et al., 1987)] or suffered from severe, disabling arthritis. For all experiments, consent was obtained from each subject in accordance with the Helsinki declaration, and all experimental work was carried out under the approval of the ethical committees of Monash University and the Kingston Centre.

**Apparatus**

Movements were performed on a pair of manual cranks, consisting of two wheels (26 cm in diameter), side by side, in the same vertical plane, with handles located 8 cm from the axis of rotation of each wheel. Subjects sat at a table with the cranks directly in front of them and the apparatus centred on the body midline, and they turned the cranks by the handles in the vertical plane. The distance between the two shoulders, across the back of each participant, was measured, and used to set the distance between the two wheels, so that the apparatus was fitted individually to each subject. The wheels were individually mounted; thus it was possible to monitor the movement of each hand independently via separate data channels. The angular position of each wheel was determined by a code-wheel and optical decoder unit, which was recalibrated before each use. The angular position of each wheel relative to a fixed reference point was sampled at 200 Hz. Upon each rotation this reference point was re-calibrated for each wheel by a light pulse. A metronome was used to pace the movements of the subjects.
**Procedure**

Eight different movement conditions were examined, involving two movement types (bimanual in-phase and anti-phase, both using the homologous muscle groups), performed at fast (2 Hz) and slow (1 Hz) speeds, with and without an external timing cue. The bimanual in-phase movement consisted of both hands starting at the top of the cranks, with the left hand moving down towards the left and the right hand towards the right, concurrently. The bimanual anti-phase task consisted of the left hand beginning at the bottom of the left crank and the right hand at the top of the right crank, with the hands moving in the same directions as the in-phase task. The subjects had to produce continuous, smooth movements for a period of 20 s for each trial.

The subjects were highly practised for all movement conditions. A practice session at the first speed, on all movement configurations, was followed by the first set of trials. After a rest the subjects practised the second speed on all movement configurations, then their movements were recorded. All subjects were requested to direct their gaze to a schematic diagram on a wall ~1 m in front of them, ~40° above the axis connecting axle of the two cranks. The schematic diagram was used to explain the required movement for each trial. Subjects were instructed to grasp the crank handles firmly in the palms of the hands at all times.

For half of the trials a metronome acted as an external cue, and the subjects were required to make one rotation per beat. For the remaining trials, the subjects were required to remember the beat of the metronome and to produce the movement at the same speed without the aid of the external cue. Subjects performed 16 trials in all, two trials for each movement type. Each trial ran for 20 s at 200 Hz, generating hand position points every 5 ms. The order of trials was counterbalanced across subjects. The total duration of the experiment was ~30 min.

**Data analysis**

**Phase histograms**

To describe the movement performance of each group the difference between the two hands was calculated every 50 ms. These data were placed into one of 24 data bins which separately represented 15° segments of the rotational circle. A phase histogram represented the data, which indicated how well the groups could perform the required bimanual task. A perfect performance for the in-phase task would score 0°, and a perfect performance for the anti-phase task would score 180°. Data on the right side of zero indicated that the right hand was slightly leading the left. Data on the left side indicated that the left hand was slightly leading the right.

The derivative of the displacement data was calculated to determine the velocity of each crank at each 50 ms interval. From such time-series data four dependent variables were calculated.

**Variation in co-ordination pattern**

This measures the ability to maintain a constant, stable relationship between the two hands. It is the standard deviation of the difference (in degrees) between the right and left hands over time, and measures interhand coupling, i.e. the variability of the difference between the left and right hands. The lower the score, the better the performance.

**Accuracy in co-ordination pattern**

This is a measure of the relationship maintained by the two hands over time. It is calculated as the mean absolute difference (in degrees) between the two hands over the 10 s recording period. A perfect performance would score zero. A measure is thus obtained of the accuracy of the co-ordination pattern of the two hands over time, in absolute terms.

**Variation in velocity**

This measure represents the stability of the movement in terms of velocity. It is the standard deviation of velocity. A low score indicates a stable well-controlled movement while a high score denotes an unstable, poorly controlled movement in terms of velocity.

**Accuracy of velocity**

This measures the mean signed difference between the target velocity (fast = 2 Hz, slow = 1 Hz) and the actual velocity. A negative score indicates movement that is too slow for the target speed, and a positive score indicates movement that is too fast.

Four conditions were employed: Group (Parkinson’s disease, control), Speed (slow 1 Hz, fast 2 Hz), Cue (on, off) and Hand (left, right), according to a four-way mixed factorial ANOVA design (Group×Speed×Cue×Hand) for the accuracy and variation in velocity measures. A three-way mixed factorial ANOVA (Group×Speed×Cue) was used to analyse the accuracy and variation in co-ordination pattern scores.

**Results**

**In-phase task**

**Phase histogram**

The histograms (Figs 1 and 2) indicate that both groups performed the required movement for the majority of time, at both speeds (most scores were around zero). The Parkinson’s disease group, however, was far more variable, spending a lower proportion of time in the correct in-phase relationship (as shown by the spread of data on the histogram). They were also less accurate than the control group, at both speeds (as shown by the reduced height of the histogram at the correct 0° phase relationship). The histograms also indicate
Bimanual co-ordination

Fig. 1 Slow movements: in-phase histograms for Parkinson’s disease (PD) and control subjects for cued and non-cued movements, at the slow speed.

Fig. 2 Fast movements: in-phase histograms for Parkinson’s disease (PD) and control subjects for cued and non-cued movements, at the fast speed.
that the Parkinson’s disease group was more variable and less accurate when the cue was off, compared with when the cue was on. This pattern of results is not shown by the control group.

**Variation in co-ordination pattern**

The Parkinson’s disease patients (26°) were significantly more variable in their movements than the control subjects (13°) $[F(1,30) = 11.033, P < 0.002]$. All subjects performed the movements at the fast (25°) speed more variably than at the slow speed (14°) $[F(1,30) = 12.768, P < 0.001]$. No significant interaction between Group and Speed was found.

There was a significant interaction between Group and Cue $[F(1,30) = 9.137, P < 0.005]$ (see Fig. 3). Control subjects performed the in-phase task with almost the same variability between the two hands for both cue on (14°) and cue off (13°) conditions. Parkinson’s disease patients, however, were more variable than control subjects for cue on (23°) and much more variable for cue off (29°). Sub-analyses (one-way ANOVA) showed that while there was no significant difference between the means for the control subjects for cue on and cue off $[F(1,15) = 0.865, P > 0.05]$, there was a significant difference between the means for the Parkinson’s disease patients $[F(1,15) = 9.450, P < 0.008]$. There was no significant interaction between Group, Speed, and Cue.

**Accuracy of co-ordination pattern**

The Parkinson’s disease patients (28°) did not perform the bimanual in-phase task as accurately as the control subjects (15°) $[F(1,30) = 7.658, P < 0.01]$. The control group’s performance was not affected by the cue being on (16°) or off (15°). The Parkinson’s disease performance of this task, however, was less accurate than that of the control subjects when the cue was on (24°) and especially when the cue was off (33°) $[F(1,30) = 1.573, P < 0.003]$ (see Fig. 4). Sub-analyses (one-way ANOVA) showed that there was no significant difference between the means for the control group for cue on and cue off $[F(1,15) = .503, P > 0.05]$. There was, however, a significant difference between the means for cue on and cue off for the Parkinson’s disease patients $[F(1,15) = 12.462, P < 0.003]$. This indicates that accuracy of movements by Parkinson’s disease patients is influenced by external cues.

**Variation in velocity**

The Parkinson’s disease patients were significantly more variable in velocity ($\pm 0.295$ Hz) than control subjects ($\pm 0.239$ Hz) $[F(1,30) = 6.833, P < 0.014]$. For all subjects the performance of the task at the fast speed ($\pm 0.315$ Hz) was more variable than at the slow speed ($\pm 0.218$ Hz) $[F(1,30) = 106.942, P < 0.001]$. There was a significant interaction between Group and Speed $[F(1,30) = 4.580, P < 0.041]$. In the slow condition the Parkinson’s disease patients ($\pm 0.256$ Hz) were significantly more variable in velocity than the control subjects ($\pm 0.180$ Hz) $[F(1,30) = 7.496, P < 0.01]$. In the fast condition the control subjects ($\pm 0.297$ Hz) were as variable as the Parkinson’s disease patients ($\pm 0.333$ Hz) $[F(1,30) = 4.019, P > 0.05]$.

**Accuracy of velocity**

Parkinson’s disease patients were able to perform this task at the same velocity as the control subjects, with and without the cue. Accuracy was measured as the mean difference between the target and actual velocities. Performance at the fast speed (mean error, 0.009 Hz) was more accurate than performance at the slow speed (mean error, 0.109 Hz), which was too fast $[F(1,30) = 9.463, P < 0.004]$.

**Anti-phase task**

**Phase histogram**

The phase histograms (Figs 5 and 6) indicate that, at the slow speed, the control subjects were able to perform the
Fig. 5 Slow movements: anti-phase histograms for Parkinson’s disease (PD) and control subjects for cued and non-cued movements, at the slow speed.

Fig. 6 Fast movements: anti-phase histograms for Parkinson’s disease (PD) and control subjects for cued and non-cued movements, at the fast speed.
anti-phase movement more successfully (i.e. peaking near 180°, the target angle) than the Parkinson’s disease patients, who peaked at 0°, i.e. in-phase. The control subjects, moreover, were able to perform the anti-phase movement with the cue turned off more accurately (i.e. with a higher peak) than when the cue was turned on. The Parkinson’s disease patients were unable to perform the anti-phase movement at the slow speed, with or without the cue. In fact the lowest point on the slow phase histogram for both cue on and cue off, for the Parkinson’s disease patients, was at 180°, the required target relationship between the two hands. They appear to have been performing the in-phase movement instead (their histogram bars are highest around the 0° phase-angle point), and, interestingly, the (incorrect) in-phase movement appears to be more accurate with the cue on than with the cue off, at the slow speed.

Because the Parkinson’s disease patients consistently peaked at 0°, i.e. 180° from the target angle, an analysis was performed on the proportion of time spent in the 15° bin around zero; a two-way ANOVA (Speed: fast or slow; Cue: on or off) was performed for the Parkinson’s disease patients, on the 15° phase angle bin representing the score from –8° to +7°. This bin represents the perfect in-phase movement. The Parkinson’s disease patients performed in an (incorrect) in-phase fashion more accurately when the speed was slow and the metronome was on (14% of the time spent performing the in-phase movement), than when the metronome was off (7% of the time spent performing the in-phase movement) [F(1,15) = 5.262, P < 0.037]. When the speed was fast, cueing had no effect, the Parkinson’s disease patients spending 8% of the time performing the in-phase movement when the metronome was on, and 7% when the metronome was off. At the fast speed neither group could perform the anti-phase movement, indicating the breakdown in normal co-ordination at the faster speed.

Variation in co-ordination pattern
No significant effects were found for this measure, indicating that independent of what relationship was actually maintained, the stability of the relationship did not vary between conditions or subject groups.

Accuracy of co-ordination pattern
The control subjects were more accurate in their performance of the anti-phase movement (difference between the two hands, 71°) than the Parkinson’s disease patients (113°) [F(1,30) = 9.954, P < 0.004]. This was to be expected considering the latter were performing in a more in-phase than anti-phase fashion.

There was no significant difference in accuracy between the fast and slow speeds overall, but there was a significant interaction between Group and Speed [F(1,30) = 1.280, P < 0.003]. There was no significant difference between the control subjects (87°) and the Parkinson’s disease patients (104°) at the fast speed [F(1,30) = 1.184, P > 0.285]. Neither group could perform this movement at the fast speed. At the slow speed the control subjects (55°) were more accurate in performing the anti-phase movement, than the Parkinson’s disease patients (121°) [F(1,30) = 2.328, P < 0.001].

The performance of both groups with the cue on (100°) was less accurate than with the cue off (84°) [F(1,30) = 8.804, P < 0.006]. When this main effect was broken down by Group, there was no significant interaction with Group and Cue. Both groups were less accurate with the cue on than with the cue off.

Variation in velocity
The control group was more stable in velocity (SD = ±0.252 Hz) than the Parkinson’s disease patients (±0.315 Hz) [F(1,30) = 5.555, P < 0.025]. The performance of all subjects was more variable in velocity at the fast speed (±0.326 Hz) than at the slow speed (±0.242 Hz) [F(1,30) = 7.999, P < 0.001]. The performance of both groups at the fast speed was more variable in velocity than at the slow speed [F(1,30) = 5.833, P < 0.022]. The Parkinson’s disease patients at the fast speed (±0.345 Hz) were not significantly different from the control subjects at the fast speed (±0.306 Hz) [F(1,30) = 2.394, P > 0.132]. At the slow speed the Parkinson’s disease patients (±0.285 Hz) were significantly more variable than the control subjects (0.199 Hz) [F(1,30) = 7.629, P < 0.01].

There was no significant main effect for Cue, in terms of variability in velocity.

Accuracy in velocity
Parkinson’s disease patients were able to perform the task at the same velocity as the control subjects. Both groups performed the anti-phase movement at the fast speed too slowly (a mean error of –0.171 Hz), and slightly too fast at the slow speed (+0.93 Hz) [F(1,30) = 45.350, P < 0.001]. There was no interaction between Group and Speed. Both groups were too slow in velocity at the fast speed, and were more accurate in velocity at the slow speed. There was no significant main effect for Cue.

The asymmetries of onset for the Parkinson’s disease patients did not have a significant effect on the accuracy of co-ordination of the in-phase, t(11) = 1.98, P > 0.05, or anti-phase, t(11) = 0.66, P > 0.05, movements.

There was no significant correlation between the Webster scores and the accuracy of co-ordination pattern by the Parkinson’s disease patients for the in-phase movement, r(15) = –0.2016, P = 0.454. However, there was a significant positive correlation between the Webster scores and the accuracy of co-ordination pattern by the Parkinson’s disease patients for the anti-phase movement, r(15) = + 0.5916, P = 0.016. Thus the higher the score on the Webster scale,
the more inaccurate the performance on the anti-phase movement.

Discussion

While Parkinson’s disease patients are clinically reported to have problems with bimanual co-ordination, the lack of consensus in previous experimental studies may reflect differences in task characteristics. Tasks with a similar movement of each hand did not pose as many problems for Parkinson’s disease patients as those which necessitated different movements for each hand. In this study, all subjects were able to maintain the required bimanual in-phase movements, at both speeds. Controls could also maintain the anti-phase movement at the slow speed, but not at the fast speed. However, Parkinson’s disease patients were not able to maintain the anti-phase movement at either of the speeds examined.

The in-phase movement, used in this experiment, is simple to perform because there is only one timing pattern. The hands complete exactly the same movement mirror-symmetrically, the homologous muscles are simultaneously active, enabling interlimb coupling, and attention may rest on one hand to which the other is coupled. The Parkinson’s disease patients were able adequately to perform this movement at both speeds, although they were significantly less accurate and less stable than control subjects in their maintenance of the in-phase relationship between the two hands. They were also more variable in velocity, even though they performed the movements at the same mean velocity as the control subjects.

The Parkinson’s disease patients could not maintain the anti-phase movement at either speed. In comparison, the control subjects were able to maintain the anti-phase movement at the slow speed, but not at the fast speed. The anti-phase movement is more complex than in-phase movement for a number of reasons. It requires specific, sequential timing of muscle activation to maintain the required difference between the two hands, and is mirror-asymmetrical. Attention may need to be continually switched in order to keep the required phase relationship between the two hands. The most crucial aspect of the movement is inter-manual timing. Anti-phase movement is effectively composed of two submovements per hand, per rotation. The hands in turn rotate to the top, constituting two sequential submovements. The patients were unable to maintain this movement adequately at either speed, with or without a cue.

Effects of external cueing were also found to be important. Parkinson’s disease patients performed the in-phase movement with much less accuracy and stability in the absence of external cues, highlighting the likely role of the basal ganglia in movements which are internally determined (Georgiou et al., 1993, 1994; Jackson et al., 1995). When an external timing cue was provided, the Parkinson’s disease patients were able to maintain the in-phase movement with more accuracy and stability, and thus with better co-ordination. During the anti-phase movement, with the external cue, they tended to perform the in-phase movement instead, at both speeds. The external cue may even have increased the effective complexity of the task; thus subjects had to perform the harder movement correctly and in time with the metronome. In the absence of an external cue, however, the Parkinson’s disease patients were still unable to perform the requisite anti-phase movement, and tended instead towards symmetrical in-phase movement, although this effect was not as strong as in the presence of the metronome signal. Studies of bimanual co-ordination on monkeys and humans with supplementary motor area (SMA) damage have also revealed such a tendency to revert to mirror-symmetrical movement, when the requisite movement is mirror-asymmetrical (Luria, 1966; Brinkman, 1981; Chan and Ross, 1988).

Unilateral SMA lesions disrupt performance of bimanual tasks in monkeys (Brinkman, 1981; Wiesendanger, 1993) and humans (Laplane et al., 1977; Freund and Hummelsheim, 1985; Dick et al., 1986; Watson et al., 1986). Mirror movements have resulted from SMA damage, and the alien hand syndrome (unintended hand movements that seem to act against the person’s reported will) can occur after lesions of both the SMA and corpus callosum, impairing bimanual co-ordination (Goldberg et al., 1981; Goldenberg et al., 1985; McNabb et al., 1988; Trojano et al., 1993; Bradshaw and Mattingley, 1995).

The SMA receives thalamocortical input from the internal segment of the globus pallidus (Hoover and Strick, 1993), and in Parkinson’s disease this output may be disrupted. The SMA may be involved in the production and control of bimanual movements (Wiesendanger, 1993). In particular Wiesendanger (1993) noted that the SMA may be involved in temporal organization and control of difficult movement sequences. Lang et al. (1990) demonstrated that there is simultaneous activation of the two primary motor cortices during simultaneous, synchronous movements, such as the in-phase movements. During sequential movements, however, additional mesial activation is observed, of the SMA. SMA activity is greater for bimanual tasks in which movements of each hand are asymmetrical rather than symmetrical (Uhl et al., 1993), or where they alternate sequentially rather than being performed simultaneously (Lang et al., 1989). Patients with unilateral SMA lesions may be particularly deficient in performing alternating movements of the two hands (Laplane et al., 1977; Freund and Hummelsheim, 1985; Dick et al., 1986). The anti-phase movement utilizes homologous arm muscles sequentially, and is mirror-asymmetrical. The anti-phase movement effectively consists of two related submovements, each requiring precise timing of muscle activation to maintain a constant, stable intermanual difference. The Parkinson’s disease patients tended to perform the in-phase instead of the anti-phase movement when the external cue was provided. The external cue may have provided a synchronizing cue which is otherwise missing but
necessary in such complex movements with disparate postures. The SMAs of both hemispheres are reciprocally interconnected, and each SMA projects to both the ipsilateral and contralateral primary motor cortices, from which individual movements are elaborated. Unilateral electrical stimulation of the SMA typically leads to bilateral movements of a fairly co-ordinated nature (Penfield and Welch, 1951; Fried et al., 1991). Electrophysiological studies have found greater SMA activity for bilateral compared with unilateral movements (Kristeva and Deecke, 1980). Such evidence supports the hypothesis that the SMA is involved in bimanual co-ordination (Wiesendanger, 1993).

Previous studies are equivocal on the ability of Parkinson’s disease patients to maintain bimanual movements. The present study, however, indicates that Parkinson’s disease patients could perform the in-phase movement on the bimanual cranks, but were more variable and less accurate in their co-ordination pattern in comparison with the control subjects. They had particular difficulty when attempting to perform the anti-phase movement (with a common timing element involving sequencing of the two hands). This suggests that the basal ganglia motor circuit may be involved in the control of bimanual co-ordination. The anti-phase bimanual movements may be commended as a possible sensitive clinical procedure to assess and quantify patient function where bimanual performance may be compromised, as in Parkinson’s disease, and where there is likely SMA damage.

References
Bimanual co-ordination


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