Hypometria in Parkinson’s Disease: Automatic Versus Controlled Processing

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Summary

Objectives: The aim was to investigate whether patients with Parkinson’s disease (PD) make movements that are of smaller amplitude when required to attend to a secondary task at the same time as performing a motor task.

Methods: Thirteen patients with idiopathic Parkinson’s disease (mean age, 67.1 yrs) and 14 healthy control subjects (mean age, 66.2 yrs) were tested. The motor task was repeated opposition of the thumb and forefinger and the secondary task was a lexical decision task.

Results: The PD patients made hypometric movements, and the amplitude was further decreased when they performed the secondary task at the same time. There was no significant change for the control subjects.

Conclusion: The unpaced motor task was less automatic for the PD patients than for the control subjects, and hence more subject to interference from a secondary task. We relate this to the underactivation of the supplementary motor cortex (SMA).

Key Words: Parkinson’s disease—Attention—Akinesia.

In a previous article, we reported that patients with Parkinson’s disease (PD) are less micrographic if they are presented with visual targets or are constantly reminded to write large letters. It was argued that these cues might act by drawing the attention of the patients to the need to produce movements of a normal amplitude. If this is so, it should be possible to show that the movements would become more hypometric if the attention of the patients was drawn to the performance of a secondary task.

It is well known that PD patients are impaired if they are required to perform two motor acts at the same time. This was shown by Schwab et al. who required the patients to press a bulb repeatedly while drawing with the other hand, and by Benecke et al. who required the patients to oppose thumb and forefinger (“squeeze”) at the same time as bending the elbow (“flex”). Recently, Morris et al. reported that the stride length of PD patients is reduced if the patients are required to repeat sentences or recite the days of the week backwards.

In all these experiments, the patients were required to perform two motor acts simultaneously. It could therefore be argued that the findings suggest an impairment in “motor planning.” The aim of this experiment was to investigate whether the amplitude of continuous movements would be decreased if the patients were distracted by a secondary task that was not a motor task. In this experiment, the patients were required to perform a lexical decision task at the same time as performing continuous flexions and extensions of the thumb and forefinger. The lexical decision task was to identify non-words in passages of continuous prose that were presented using a loudspeaker. Continuous prose was deliberately chosen so that the pacing of the words would not entrain the pacing of the finger movements.

We compared three conditions. In the “paced” condition, the subjects repeatedly opposed finger and thumb with the pacing being given by tones. In a second, “unpaced” condition, the tones only continued for 5 seconds and the subjects were then required to continue performing at the same rate. In the third, “simultaneous” con-
dition, the subjects performed the motor task unpaced, but were required to perform the lexical decision task at the same time.

**METHODS**

**Subjects**

We tested 13 patients with mild to moderate idiopathic Parkinson's disease and 14 control subjects. Eleven of the 13 patients and all of the control subjects participated in the experiment described in a previous article. The mean age for the control group was 67.1 years (standard deviation [SD] 8.31) and for the patients 66.6 years (SD 9.16). All subjects except one patient were right-handed. Table 1 presents details of individual patients, including Webster scores and Hoehn and Yahr stages.

The patients were stable on individual drug regimens at the time of testing and none were dyskinetic. The time of testing was standardized to 2½ to 3 hours after the last dose of dopaminergic medication. There were no differences between the patients and control subjects in three subtests of the WAIS; vocabulary, similarities, and digit span. None of the control subjects had any known neurolologic impairment or were taking any medication that affects the central nervous system. All subjects gave informed consent, and ethics committee approval was obtained for the study.

**Apparatus**

The apparatus consisted of two metal bars connected to a standard potentiometer (10 kΩ). The bars were arranged so that one of them was rigidly fixed to the outer casing of the potentiometer and the other was connected to its spindle. During testing, one bar was attached to the index finger and the other was attached to the thumb so that any opposing movement of these digits rotated the spindle relative to the case of the potentiometer. A voltage gradient was produced by applying a +10-volt supply to one end of the resistive track of the potentiometer. The other end was connected to a 0-volt terminal, and the slider was connected to an analog input converter in the computer. Thus, any movement of the spindle, which was directly connected to the slider, produced a varying voltage output. In this way, a maximum change of angle of 107° produced a voltage difference of 5.44 volts.

The voltage gradient of the potentiometer and the corresponding time were read into the computer every 8 msec. The apparatus was recalibrated weekly.

**Procedure**

The bars of the apparatus described above were attached to the index finger and thumb of the dominant hand. The subject was asked to rest the elbow on the arm of the chair, keeping the forearm upright. The task consisted of opposing the index finger and thumb at a rate of approximately 2 per second. When the subject was ready, the experimenter started the computer. After 2 seconds, a tone marked the beginning of the trial. There were three conditions. For each condition, the subjects made the required movements for 40 seconds.

The first condition was “paced.” The computer generated tones every 500 msec for 40 seconds. The subjects were required to make a movement at each pacing tone. The second condition was “unpaced.” The computer generated tones for the first 5 seconds at the same rate as in the previous condition. The subjects were instructed to keep pace with the tones. They were also informed that the tones would stop, and that after that they should maintain approximately the same rate. The subjects

### Table 1. Details of parkinsonian patients

<table>
<thead>
<tr>
<th>Patient no.</th>
<th>Age (yrs)</th>
<th>Onset (mos)</th>
<th>Webster</th>
<th>WAIS</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Brad</td>
<td>Rig</td>
</tr>
<tr>
<td>1</td>
<td>63</td>
<td>128</td>
<td>2</td>
<td>2</td>
</tr>
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<td>2</td>
<td>48</td>
<td>6</td>
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<td>2</td>
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<td>2</td>
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<td>120</td>
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</tr>
<tr>
<td>13</td>
<td>68</td>
<td>106</td>
<td>2</td>
<td>2-3</td>
</tr>
</tbody>
</table>

Brad, bradykinesia; Rig, rigidity; Trem, tremor; Total, total Webster score; HY, Hoehn-Yahr staging; Voc, vocabulary (WAIS); Sim, similarities (WAIS); DS, digit span (WAIS). WAIS age-scaled scores are presented. MG, complaint and documented micrographia in everyday life.
were told not to count mentally while performing the movements.

The last condition was "simultaneous." The motor task was the "unpaced" task but a lexical decision task was presented at the same time. In the lexical decision task, the subjects were required to report at the end of the trial the number of non-words that appeared in passages of prose. The passages were recorded on a tape recorder by an English speaker. Each passage contained 3–5 non-words. The playback of the passages was started 5 seconds after the beginning of the trial. One passage was played on each trial. The prose passages are given elsewhere.

Before the experiment began, there was a training session. A 10-minute break was given between the end of the training session and the beginning of the experiment. There were two trials for each condition. Each condition was tested on a different day in the order "unpaced," "paced," and "simultaneous."

Data Analysis

The raw data consisted of a succession of points expressing the distance between the two metal bars (in degrees). These points were plotted against the corresponding times, and the successive minimum and maximum distances between the two metal bars were chosen with a cursor. The first value when the distance between the bars started to increase was taken as the beginning of a movement (minimum). The first point at which the distance between the bars stopped increasing, before starting to decrease again, was taken as the maximum. The estimated error of these measurements of minima and maxima was smaller than 0.5°. The maxima and minima and the corresponding times were used to calculate the amplitude of the movements and their duration.

Movement amplitude was the difference between the distance between the bars at the beginning of the movement (minimum) and the distance between the bars at the end of the movement (maximum) in degrees. Rate was the number of movements produced in a given time interval divided by the duration of that interval and was expressed in movements per second (mov/sec). Velocity was calculated by dividing the movement amplitude by its duration (the difference between the times corresponding to the minimum and maximum distance between the bars which delimited a movement) and was expressed in degrees per msec.

The total duration of a trial was 40 seconds. Data for the initial 10 seconds of each trial were discarded because the subjects were becoming accustomed to the task. This left a 30-second test period.

RESULTS

Rate

A 2 × 3 ANOVA showed that overall the patients produced movements at a slightly higher rate than the controls (F [1,25] = 12.39, p < 0.01). Whereas Figure 1A shows that for the patients the rate tended to be higher in the simultaneous condition, neither the main effect of condition nor the interaction between condition and group were significant.

Amplitude

Overall, the patients produced smaller movements than the control group (F [1,25] = 8.80, p < 0.01). The

![Graphs showing results for patients (triangles) and control subjects (circles) in "unpaced" (Unp), "paced" (Pac), and "simultaneous" (Sim) conditions for (A) rate, (B) amplitude, and (C) velocity.](image-url)
main effect of condition was also significant ($F [2,50] = 18.82, p < 0.001$) and so was the interaction between group and condition ($F [2,50] = 136.32, p < 0.02$). The interaction was the result of the fact that the effect of condition was significant for the patients ($F [2,24] = 24.77, p < 0.001$) but not for the control group (Fig. 1B).

We looked at the interaction between group and condition, including only unpaced and simultaneous, in the ANOVA. The interaction remained significant ($F [1,25] = 7.22, p < 0.02$), reflecting the fact that the difference between simultaneous and unpaced was significant for the patients (df = 12, $t = 6.56, p < 0.001$) but not for the control group.

If only unpaced and paced were included in the ANOVA, the interaction (group versus condition) approached significance ($p = 0.06$). As can be seen in the graph, for the control subjects, there was a slight increase of movement size from unpaced to paced, whereas for the patients, there was a slight decrease from one condition to the other. These differences between conditions were not significant for the control subjects but approached significance for the patients ($p = 0.08$).

All the results for amplitude were confirmed if ‘rate’ was included as a covariate in the analysis: the differences observed in terms of amplitude are not therefore the result of simply differences in rate of movement execution.

**Mean Velocity**

The movements were slower overall for the patients than for the control group ($F [1,25] = 4.73, p < 0.05$). The main effect of condition was also significant ($F [2,50] = 6.51, p < 0.01$), but the interaction between group and condition was not significant. The movements were slower overall in simultaneous than in unpaced (df = 26, $t = 3.19, p < 0.01$), but the difference between unpaced and paced was not significant (Fig. 1C).

**Lexical Decision Task**

The frequency of correct responses was similar in the two groups both when the lexical decision task was performed on its own and when it was performed with the motor task.

When the lexical decision task was performed on its own, 69.5% of the patients and 57% of the control subjects reported the correct number of non-words. When the task was performed at the same time as the motor task, the figures were 69% of the patients and 68% of the control subjects.

The differences between groups was tested for each presentation of the lexical decision task using Chi square. There were no significant differences between the groups whether the lexical decision task was performed with the motor task or on its own. There was also no significant difference for either group between the scores when the lexical decision task was performed with the motor task or on its own.

**Correlation With Severity of Disease**

We calculated the reduction in amplitude in the simultaneous condition compared with the unpaced condition, and correlated this reduction with the Webster scores. The correlation was 0.68 (Spearman rank difference correlation, $p < 0.05$).

**DISCUSSION**

The PD patients produced hypometric movements when required to repeatedly flex and extend the thumb and forefinger. They made these movements at a slightly higher rate than the control subjects whether the task was paced or unpaced. However, the fact that the patients made movements of smaller amplitude was not simply the result of this slight increase in rate.

The addition of pacing cues (paced condition) did not significantly affect either the rate or the amplitude of the movements. Georgiou et al. reported that, when required to make a series of choices between pairs of buttons, PD patients were quicker to choose between the next two buttons in the sequence if the movements were paced by a metronome. However, in the present experiment, the PD patients performed the movements at a slightly higher rate than the control subjects, perhaps because their movements were smaller. It is still true that the amplitude of the movements of the PD patients did not increase when external pacing cues were given. It has been shown in other studies that PD patients perform movements of normal amplitude if given external cues that specify the required amplitude, but there are no studies which show that the movements are normal in amplitude if they are paced.

When performing the secondary task at the same time, the PD patients reduced their movements to a greater extent than did the control subjects. However, for the lexical decision task, there was no significant difference between the performance of patients and control subjects irrespective of whether the task was performed on its own or at the same time as the motor task. The greater reduction of movement amplitude for the patients when they performed the secondary task was not the result of their having a greater problem with the secondary task.

These results suggest that the fact that PD patients are poor at performing two motor acts simultaneously is not solely the result of a specific impairment in the planning of two movements at the same time. The patients
are also impaired at performing one motor act when required to perform a non-motor task at the same time. The effect of distraction can be explained in terms of the distinction that psychologists draw between ‘automatic’ and ‘non-automatic’ or ‘controlled’ processing.1,11,12 The degree to which a task is automatic can be measured by assessing the degree of interference shown when a secondary task is performed at the same time. For example, normal subjects are able to generate verbs at the same time as performing an overlearned motor sequence, but if they are required to generate verbs during the learning of a motor sequence, they make errors on the motor sequence task.13 In the present experiment, the unpaced task was relatively automatic for the control sequence, but if they are required to generate verbs during the learning of a motor sequence, they make errors on the motor sequence task.13 In the present experiment, the unpaced task was relatively automatic for the control subjects: the trend toward a smaller amplitude for the simultaneous compared with the unpaced condition was not significant. For the PD patients, on the other hand, there was considerable interference during dual task performance, and this implies that the task was not automatic for these patients. An alternative possibility is that the task involved controlled processing for both groups, but that the processing resources are reduced in patients with Parkinson’s disease.

The fundamental cortical abnormality in PD patients is the underactivation of the supplementary motor cortex (SMA).14,15 The SMA is strongly activated in normal subjects during self-paced movement16 and is underactivated in PD patients when they perform self-paced movements.17 Furthermore, the SMA is especially involved in ‘open loop’ performance where a motor task is run off automatically and without external cues that specify the sequence of movements.18,19

Oliveira et al.1 have shown that PD patients can compensate for their poor performance if they are given visual targets to specify the correct amplitude or constant reminders that they should produce movements of large amplitude. Morris et al.4 have also reported that the patients can compensate when walking if they are shown the desired stride length, and are then required to guide their performance by constantly reminding themselves of that amplitude. These effects may occur because the patients are encouraged not to respond automatically but to respond under attentional control.

The question arises as to why PD patients can not fully compensate even when they are not given external cues to direct their attention to the task. Brown and Marsden20 have suggested that processing resources might be reduced in Parkinson’s disease, with the consequence that the patients do not attend as efficiently as normal subjects. They have shown that the reaction time of PD patients on the Stroop task was prolonged when they had to generate random numbers at the same time.20

D’Esposito et al.21 reported that the anterior cingulate and dorsal prefrontal cortex are activated during dual task performance, as measured by positron emission tomography (PET). There is substantial evidence from PET that these areas are involved in attention,1,3,2,12 and both areas are known to be underactivated in Parkinson’s disease.14,17,23

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REFERENCES


