Bimanual simultaneous motor performance and impaired ability to shift attention in Parkinson's disease

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Abstract

The ability to share time and to shift attention between bimanual simultaneous motor tasks were studied in 18 patients with Parkinson's disease (PD) and 19 age- and intelligence-matched controls. The task consisted of drawing triangles with the dominant hand and squeezing a rubber bulb with the non-dominant hand. Motor performance was measured using the variables: amplitude of squeezing, frequency of squeezing and velocity of drawing triangles. After eliminating variance due to baseline differences in single-handed performance, the bimanual simultaneous performance of PD and controls turned out to be similar to the frequency of squeezing and the velocity of drawing triangles. The amplitude of squeezing, however, differed between the two groups: it was significantly reduced in PD. Arguably the disturbance in the bimanual performance of PD patients was not due to a disorder of time sharing, but to a decreased ability to shift attention from the visually cued task to the non visually cued task. The results agree with current evidence that PD patients are more impaired when they have to rely upon internal control for the regulation of shifting attention than when external cues are available.

Temporal and spatial processing is involved in the simultaneous performance of two separate single-handed tasks. The timing of bimanual simultaneous tasks is a function of one generalised time-programme,¹⁻⁵ a phenomenon also referred to as time-sharing.⁴ The spatial performance of both tasks is executed by two separate concurrently running motor-programmes that are controlled by shifting attention from one task to the other.^{4,6}

Patients with Parkinson's disease (PD) are known to have much more difficulty than controls when simultaneously performing two separate single-handed tasks, even though they can perform each of these tasks separately.⁶⁻¹⁰ Their performance turns out to be task dependent: separate single movements are executed simultaneously in PD,^{6,10} but repetitive movements sequentially.⁹ PD patients are apparently disabled when simultaneous repetitive movements are involved. Correct performance of such repetitive simultaneous tasks depends on the capability of

sharing time and shifting attention. To our knowledge, time-sharing during repetitive simultaneous movements has not been studied in PD. As far as the ability to shift attention is concerned, several authors reported that PD patients have problems with shifting set,^{7,11-19} set being defined as a process of focussed and sustained attention predisposing a subject to respond in one way when several alternatives are available.^{17,18} Such shifting deficiency is associated with hypofunctioning of the dopaminergic system.²⁰

In this study, a simplified test of Schwab *et al*⁹ was used to evaluate both time sharing and shifting attention. The dominant hand drew triangles, while the non-dominant hand at the same time repeatedly squeezed a rubber bulb. Drawing fixed triangles is strongly determined by external cues, while squeezing of a rubber bulb almost entirely depends on internal control. We therefore expected that squeezing in PD patients would be more impaired than drawing triangles, since PD patients are impaired when they have to rely upon internal control for regulating attention, but are relatively unimpaired when external cues or guidance are given.^{16,19,21}

Subjects

Eighteen patients with idiopathic PD (without thalamotomy) and nineteen controls were studied. All patients regularly attended the outpatient department of movement disorders and gave their informed consent. The patients had been clinically stable for at least one month before the examination. Relevant data and disease factors are summarised in table 1.

PD patients and controls were well matched for age, intelligence and attention. Five subtests of the WAIS were used to assess intelligence (score (SD)): Vocabulary (PD: 36.12 (9.74); controls: 41.05 (9.02)), Similarities (PD: 16.33 (5.34); controls: 17.47 (4.17)), Picture Completion (PD: 10.50 (3.09); controls: 11.37 (3.51)), Block Design (PD: 10.67 (4.43); controls: 12.16 (5.19)) and Digit Span (PD: 11.78 (2.73); controls: 12.32 (3.84)). Deficits in attention were assessed with the Stroop Colour Word Test by subtracting the duration of Stroop Colour Word Test-2 from that of the Stroop Test-3^{22,23} (PD: 58.83 (20.70); controls: 49.32 (17.00)). The differences between the group means were not significant (MANOVA, SPSSX: $F = 0.85$, $df = 6$ and 30 ; $p > 0.05$). Depression was excluded by clinical examination and enquiries among family members.

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Received 23 September 1988
and in final revised form 7
November 1989.
Accepted 11 December 1989

Table 1 Demographic data and disease factors in Parkinson's disease (PD)

Pat nr	Age yrs	PD yrs	Levodopa		Antichol		Webster		Hypokin		H-Y stage
			yrs	mg/d	yrs	mg/d	R arm	L arm	R arm	L arm	
1	63	5.5	0.25	400 ¹	4.5	1 ⁴	2	5	1	2	3
2	66	3.0	—	*	2.5	150 ³	4	4	2	2	3
3	70	4.0	—	—	—	—	3	2	1	1	1
4	69	1.5	0.25	400 ¹	—	—	6	2	2	1	2
5	67	4.5	—	*	2.5	150 ³	2	3	1	1	3
6	71	6.0	1.5	400 ¹	—	—	4	3	1	1	2
7	47	5.0	—	*	2.5	150 ³	1	1	1	1	1
8	50	6.5	2.0	300 ¹	2.5	150 ³	2	2	1	1	2
9	51	5.0	—	*	2.5	150 ³	6	2	2	1	2
10	59	1.5	—	*	1.5	200 ³	5	5	2	2	2
11	41	5.5	—	—	—	—	3	4	1	1	2
12	47	6.5	5.5	1600 ²	—	—	3	4	2	2	3
13	58	7.5	5.0	400 ¹	6.5	150 ³	7	3	3	1	3
14	70	14.5	6.0	3200 ²	13.0	300 ³	5	4	2	2	3
15	63	5.0	3.0	200 ¹	—	—	5	7	2	2	3
16	67	4.0	3.0	200 ¹	3.5	1 ⁴	2	7	1	2	2
17	68	11.5	6.0	3500 ²	9.0	4 ⁵	5	7	2	2	4
18	64	7.0	5.0	600 ¹	6.0	150 ³	2	2	1	1	1
mean	60.8	5.8	3.3				3.7	3.7	1.5	1.4	2.3
SD	9.3	3.1	2.3				1.6	1.8	0.6	0.5	0.8

Abbreviations: Webster: sum of tremor, hypokinesia and rigidity scores of upper extremity according to Webster rating scale. Hypokin: Webster hypokinesia score of the upper extremity. R: right side, L: left side. H-Y: Hoehn-Yahr scale. mg/d: mg/day; antichol: anticholinergics.

¹: Levodopa plus decarboxylase inhibitor; ²: levodopa; ³: orphenadrine-HCl; ⁴: dextimide; ⁵: benztropine; *: amantadine 200 mg.

Methods

Single-handed performance was assessed by means of two tasks: squeezing with the non-dominant hand (Sq) and drawing triangles with the dominant hand (Tr). Bimanual simultaneous performance was assessed by two tests: simultaneously squeezing and drawing triangles (Sq + Tr) and simultaneously squeezing and writing the letter e (Sq + ee). The single-handed and the bimanual tests lasted 15s each.

The tests were administered in the following constant order: 1 Squeezing with non-dominant hand (Sq): subjects were instructed to squeeze the bulb repeatedly and as quickly as possible by fully opening and closing the hand. This task served as the baseline squeezing performance.

2 Drawing triangles with dominant hand (Tr): subjects were instructed to connect without interruption, and as quickly as possible, the fixed angle points of a triangle with 9 cm sides. This task served as the baseline triangle performance.

3 Sq and Tr simultaneously (Sq + Tr): subjects squeezed (Sq) with the non-dominant hand while the dominant hand simultaneously drew triangles (Tr).

4 Sq and ee simultaneously (Sq + ee): to ensure that a decrease in performance was not due to the complexity of the tasks, subjects also performed a simpler test (Bloxxham *et al*²⁴). In this test the dominant hand wrote a series of lower case e's while the non-dominant hand was squeezing.

All ergograms were recorded with an electrowriter which transformed the two-dimensional movements of the dominant hand into the one-dimensional movements of the recording pen. The recorded distance was proportional to the actual performance. Only a minimal effort was required for squeezing the bulb. Subjects were seated in a quiet room

with only the experimenter present. The experimenter first demonstrated the standard procedure, after which the subjects practised each test twice, each trial lasting about 10s. This appeared to be sufficient for familiarising them with the technical equipment. There was a 60s break between the performances. Characteristic performance by controls and PD patients are shown in figs 1A, B.

Design and data analysis

The following three variables were studied: 1) Amplitude of Sq, that is, mean excursion of the recording pen in cm. 2) Frequency of Sq, that is, number of squeezes per 5s. 3) Velocity of drawing triangles, that is, trajectory of the recording pen in cm/5s. The recordings did not allow for accurate measurements of the velocity of writing the lower case e's. Performance during each test was analysed from the first recorded movement and not from the moment at which subjects were instructed to start.

The data were collected according to a design, in which we focussed on differences between PD patients and controls for bimanual simultaneous motor performance. By contrasting bimanual with single-handed performance confounding baseline differences in single-handed performance were eliminated. In our paradigm there was one between-subjects factor with two levels: controls and PD. Motor performance was a within-subjects factor also with two levels: single-handed performance and bimanual simultaneous performance. The analysis of variance of the resulting repeated measures design was based on a multivariate approach in which bimanual performance was compared with single-handed performance by means of difference scores.²⁵ Since motor performance was measured by a number of variables, there were several difference scores for the contrast of single-

Figure 1A Single-handed and bimanual simultaneous performance in a control. From left to right: single-handed squeezing (lower trace), single-handed drawing of triangles (upper trace), squeezing and simultaneous drawing of triangles, and squeezing and simultaneous writing of the letter 'e'.

Figure 1B Single-handed and bimanual simultaneous performance in Parkinson's disease. Legends see fig 1A.

Figure 2 Mean and SD of amplitude of squeezing (Sq), frequency of Sq and velocity of drawing triangles (Tr) during single-handed (SHMP) and bimanual simultaneous motor performance (BSMP) in patients with Parkinson's disease (PD) and controls (CS).

handed and bimanual performance. Both multivariate and univariate statistics are reported. Pearson correlation coefficients were used to assess the correlations between the variables of motor performance. The analysis was performed by the SPSSX procedure MANOVA.²⁶

Results

Correlations between amplitude of Sq, frequency of Sq and velocity of Tr.

Performance Sq was measured with two variables: amplitude and frequency. During single-handed Sq these variables were not significantly correlated in PD ($r = 0.13$, $p > 0.05$). In controls the amplitude of Sq was inversely proportional to the frequency of Sq ($r = -0.46$, $p < 0.05$). In the Sq+ee and Sq+Tr tests, there was no correlation between amplitude and frequency of Sq in either PD (Sq+ee: $r = 0.37$, $p > 0.05$; Sq+Tr; $r = -0.25$, $p > 0.05$) or controls (Sq+ee: $r = -0.25$, $p > 0.05$; Sq+Tr: $r = -0.38$, $p > 0.05$). In both groups the amplitudes of Sq in Sq+ee and Sq+Tr were correlated (PD: $r = 0.79$, $p < 0.001$; controls: $r = 0.59$, $p < 0.01$). The same held true for the frequencies of Sq in Sq+ee and Sq+Tr (PD: $r = 0.49$, $p < 0.05$; controls: $r = 0.85$, $p < 0.001$). In Sq+Tr velocity of Tr correlated with frequency of Sq in both PD ($r = 0.43$, $p < 0.05$) and controls ($r = 0.73$, $p < 0.001$). There was no correlation between the amplitude of Sq and the velocity of Tr in either group. (PD: $r = 0.16$, $p > 0.05$; controls: $r = -0.22$, $p > 0.05$).

Single-handed performance

The results of single-handed performance in PD and controls are shown in table 2. Both groups differed significantly as shown by a multivariate test (Wilks' Lambda = 0.31, $F = 11$, $df = 3$ and 33 , $p < 0.001$). During single-handed Sq the amplitude of Sq in PD equalled 90% of the amplitude of Sq in controls ($F = 4.90$, $df = 1$ and 35 , $p < 0.05$). The difference in frequency of Sq was greater: frequency of Sq in PD equalled 62% of the frequency found in controls ($F = 17.27$, $df = 1$ and 35 , $p < 0.001$). Finally, the difference in the velocity of drawing Tr was most striking: velocity in PD only equalled 51% of that displayed by the controls ($F = 20.80$, $df = 1$ and 35 , $p < 0.001$).

Bimanual simultaneous performance of PD patients versus controls

Bimanual simultaneous performance of PD patients was compared with that of controls (table 2, fig 2).

Our main interest was in differences in bimanual motor performance over and above differences in baseline performance. This was achieved by using difference scores between variables of single-handed and bimanual performance as dependent variables in the analysis of variance (see design and data analysis). The data are shown in table 3. PD patients and controls appeared to differ significantly for the set of difference scores as a whole (Wilks'

Table 2 Motor performance of PD patients and controls in single-handed and bimanual simultaneous tasks

Task	Variable	CS mean (SD)	PD mean (SD)	P of F PD vs CS
Single-handed:				
Sq	ampl Sq (cm/5s)	9.9 (0.2)	8.9 (1.9)	<0.05
Sq	freq Sq (n/5s)	7.3 (2.4)	4.5 (1.4)	<0.001
Tr	vel Tr (cm/5s)	38.5 (10.4)	19.8 (9.3)	<0.001
Bimanual simultaneous:				
Sq + Tr	ampl Sq (cm/5s)	9.6 (0.6)	6.1 (3.3)	*
Sq + Tr	freq Sq (n/5s)	6.7 (2.2)	3.3 (1.2)	*
Sq + Tr	vel Tr (cm/5s)	33.4 (10.3)	15.6 (8.0)	*
Sq + ee	ampl Sq (cm/5s)	8.5 (1.2)	4.9 (2.5)	*
Sq + ee	freq Sq (n/5s)	7.5 (2.0)	4.8 (1.9)	*

Abbreviations: PD: Parkinson's disease; CS: controls; Sq: squeezing; Tr: drawing triangles; ee: writing e's; ampl: amplitude; freq: frequency; vel: velocity. *See table 3.

Table 3 Difference scores between single-handed and bimanual simultaneous performance of PD patients versus controls

Task	Variable	CS mean (SD)	PD mean (SD)	P of F PD vs CS
Sq vs Sq + Tr	ampl Sq (cm/5s)	-0.3 (0.6)	-2.8 (2.5)	<0.05
Sq vs Sq + Tr	freq Sq (n/5s)	-0.6 (1.3)	-1.2 (1.4)	ns
Sq vs Sq + Tr	vel Tr (cm/5s)	-5.1 (9.9)	-4.2 (7.3)	ns
Sq vs Sq + ee	ampl Sq (cm/5s)	-1.4 (1.2)	-4.0 (2.1)	<0.001
Sq vs Sq + ee	freq Sq (n/5s)	0.2 (1.7)	0.3 (1.8)	ns

Legends: see table 2.

Lambda = 0.53, $F = 6.97$, $df = 5$ and 31 , $p < 0.001$). The univariate statistics revealed that the effect resided in a reduction of the amplitude of Sq: this reduction was much greater in PD patients than in controls, both in Sq + Tr ($F = 21.34$, $df = 1$ and 35 , $p < 0.001$) and in Sq + ee ($F = 5.95$, $df = 1$ and 35 , $p < 0.05$). The difference scores of the frequencies of Sq and the velocities of Tr did not differ significantly between patients and controls. In both groups the frequency of Sq in Sq + ee tended to increase with respect to single-handed squeezing (fig 2). Although this phenomenon did not show statistical significance, it remained remarkable because it was present in both groups.

Discussion

Single-handed performance

As the main purpose of this study was to focus on bimanual performance, we will not give a lengthy discussion on single-handed performance. The PD patients clearly had hypokinesia, showing a significantly lower frequency and amplitude of Sq than controls (table 2). In other patients with extreme hypokinesia, curves of comparable bulb ergograms showed fatigue,²⁷ which is defined as gradually decreasing amplitude with successive movements.^{27,28} However, in our patients fatigue did not play a major role: random variations in amplitude were much more striking than successive drops in amplitude (fig 1). The relatively low levels of disability in our PD patients could be one explanation for our results (table 1). The PD patients also showed bradykinesia, as manifested by a reduced velocity in their single-handed Tr. When the variables of single-handed movements are considered, the velocity of movement was most profoundly affected in PD. There were not only clear differences between PD and controls in the means of the variables, but also in the variances. In our

opinion, the latter differences also reflected well-known difficulties in executing a motor plan in PD.²⁹⁻³³

Bimanual simultaneous performance

Controls usually cannot perform two tasks together as well as they can separately because the tasks may interfere with each other.⁴ Given previous reports on impaired bimanual simultaneous performance in PD,⁶⁻¹⁰ it is most striking that PD patients in Sq + ee and in Sq + Tr showed the same changes in the frequencies of Sq as controls. The same is true for the velocity of Tr in Sq + Tr. In PD patients only the reduction in the amplitude of Sq exceeded the range of interference in controls, both in Sq + ee and in Sq + Tr (table 3, fig 2).

Our model comprises the concepts of a generalised time-programme and of separate concurrently running motor-programmes. Bilaterally generalised programmes are characterised by an invariant interlimb ratio of the pertinent variable.^{6,34} On the contrary, if a variable has a variant interlimb ratio, then the pertinent aspect of movement is supposedly executed by separate concurrent programmes.^{6,34} In the latter case, performance depends on the ability to shift attention from one task to the other while carrying them out.⁴ In both groups the frequency of Tr in Sq + Tr (the frequency which with sides were drawn being naturally proportional to the velocity of Tr) correlated with the frequency of simultaneous Sq. This may indicate an intrasubject invariant interlimb ratio and, hence, a generalised time-programme. On the other hand, since the correlation existed between subjects this might have reflected that the frequency with which individuals simultaneously performed squeezes and triangles depended on whether they were fast or slow types, irrespective of interlimb linkage. The fact that the ratio of the frequency of Sq to the frequency of drawing sides of Tr (that is, velocity of Tr) did not differ significantly between PD ($=4.7$) and controls ($=4.9$) suggested task specific invariant interlimb linkage. Moreover, the frequency of Sq varied with the type of task carried out by the dominant hand in both groups: frequency of Sq tended to increase in Sq + ee and decreased in Sq + Tr. Apparently, in both PD and controls the type of task of the dominant hand determined the pace of Sq. These results not only suggest that both groups adapted the timing of the one hand to the other, but also that both groups adapted it in the same way, indicating that PD patients constructed a generalised time-programme as controls supposedly do.¹⁻⁵

Such a bilaterally generalised time-programme in Sq + Tr indicates that Sq and Tr were executed simultaneously in PD. In fact, most of our patients drew continuously: their ergograms of ee and Tr showed hardly any gaps. Gaps would be obvious if the bimanual tasks were executed sequentially in Sq + ee and Sq + Tr. This observation is contrary to those of Schwab *et al*⁹ that PD patients do not perform repetitive movements simultaneously, but sequentially. However, it must be noted

that our drawing test was less difficult than the one used by Schwab *et al*; the instruction to draw perpendicular lines in the triangle being omitted. Their observations probably hold true for more complex tasks.

During bimanual simultaneous performance, the frequency and the amplitude of Sq did not correlate in either group. This indicates that these variables represented independent processes. The observation that in controls both variables were negatively correlated during single-handed Sq only indicates that time constraints did induce mutual dependency.⁵ These results agree with our frame of reference that both variables corresponded to distinct processes in the brain, that is, frequency corresponded to time-sharing and amplitude to spatial performance.

In Sq + Tr the amplitude of Sq did not correlate with the spatial performance of Tr: although all subjects did in fact draw Tr accurately according to the fixed scheme, amplitudes of Sq varied clearly (table 2, fig 2). This variant interlimb ratio agrees with the conclusions of Keele⁵ and Poulton⁴ that the spatial performances of separate bimanual simultaneous tasks are not executed by one generalised motor programme, but by two concurrent motor programmes. Correct performance of such concurrent motor programmes relies on the ability to shift attention between both tasks.^{4,6} Because in both Sq + ee and in Sq + Tr the reduction in the amplitude of Sq was significantly greater in PD than in controls, we conclude that the PD patients had a diminished capacity to shift their attention to Sq.

The question remains as to why there was no significant difference between PD and controls in the reduction of velocity of Tr during Sq + Tr, compared with single-handed Tr (table 3, fig 2). PD patients apparently concentrated on Tr and did not shift attention to Sq, presumably because visual cues or guidance, as present in Tr, take priority over non-visual, that is, sensory ones, as present in Sq.^{4,35} Such a procedure yields further evidence that PD patients depend on external cues or guidance to shift from one movement to another.^{16,23,31,32,36} They fail to shift attention when they have to rely upon internal control^{16,19,20} as was the case in Sq in Sq + Tr: Sq lacked imperative external cues or guidance to prompt attention and to divert it from Tr.

In our paradigm all subjects had to squeeze a rubber bulb. Squeezing did not require much effort, and so we looked upon the amplitude of Sq as a variable of spatial performance, this variable representing the trajectory of hand and finger movements. Nevertheless, due to the construction of the technical equipment, the rubber bulb also transduced some force. Hence, theoretically, the amplitude of Sq comprised some characteristics of the variable force, which would imply that the patients had difficulty controlling the force they put into their movement, because they could not pay attention to it. However, we certainly did not measure isometric squeezing. As far as we could judge from our own experience and from

that of the patients and controls, the greater part of squeezing resulted from isotonic muscle contraction. But, what is more important, the main purpose of this study was to evaluate the ability to shift attention between two simultaneous motor tasks. The question of whether the amplitude of Sq represented spatial performance or force did not influence our conclusions in that respect: in both cases an impairment of shifting of attention will produce a lower amplitude of Sq.

The deficit in bimanual simultaneous performance in Sq + Tr did not correspond to the complexity of the task: the amplitude of Sq in Sq + ee was also affected (fig 2) despite the fact that PD patients performed ee more easily than Tr (Bloxxham *et al*²⁴). Nor could simple fatigue²⁷ account for this impairment. If fatigue played a prominent role in the performance of the bimanual tasks, the velocity of Tr would also be affected. Certainly, the velocity of Tr was reduced in Sq + Tr in PD patients, but only to the same degree as seen in controls (table 3, fig 2).

We conclude that in PD the disturbance of bimanual simultaneous performance of the present tasks was not due to a decreased ability to share time between the two tasks. The deficit in bimanual simultaneous performance was, however, apparently caused by the fact that PD patients were unable to shift their attention sufficiently from one of the simultaneous tasks to the other. These experiments yield further evidence that PD patients are more impaired in the regulation of their attention when they have to rely upon internal control than when external visual cues or guidance are available.

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