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Slowing of reaction time in Parkinson's disease: the involvement of the frontal lobes

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Abstract

This study investigated the possibility that the previously mixed findings relating to cognitive deficits in Parkinson's disease might be attributable to inhomogeneity within the patients sampled, with attentional deficits occurring only for those Parkinson's patients who also have additional frontal lobe impairment. Twenty-five patients with idiopathic Parkinson's disease were classified as showing frontal dysfunction, or not, on the basis of their performance on the Wisconsin Card Sorting Test and the picture arrangement subtest of the WAIS. The two groups, and a control group of normal elderly subjects matched for age and IQ, undertook tests of visual attention designed to dissociate baseline response speed from central information processing speed. Error rates did not differ between the groups. Performance of the non-frontally impaired Parkinson's group was indistinguishable from that of the controls. By contrast, the 'frontally impaired' Parkinson's group responded significantly more slowly than the controls. Further analyses indicated that for the frontally-impaired Parkinson's group, information processing and automatic functions were unimpaired but there was a generalised slowing (as reflected by increased baseline response time) which may represent a non-specific global cognitive impairment. These findings suggest that the frontal lobes may be implicated in slowed response speed in Parkinson's disease. © 1999 Elsevier Science Ltd. All rights reserved.

Keywords: Parkinson's disease; Cognitive impairment; Attention; Visual search

1. Introduction

Parkinson's disease (PD) is primarily a disorder of motor control. However, research over the last two decades has provided an extensive body of evidence associating frontal lobe type cognitive deficits with the disease [5, 8, 15, 36, 41, 43]. A number of authors have suggested that loss of attentional control may underlie many of these cognitive deficits [6, 7, 10, 11, 34, 38]. For example, Brown et al. [6] suggested that the factor most associated with underlying cognitive dysfunction was a disturbance of affect/arousal. On visual attention tasks, Sharpe [38] found that patients with PD were more prone to interference in the presence of distractor items than normal control subjects.

Attentional control is believed to rely on the frontal lobes, particularly the dorsolateral areas of the prefrontal cortex [16, 32]. General lesions to the frontal regions can result in disorders of attention and arousal [20, 32], and the connections between the prefrontal cortex and thalamus have frequently been implicated in arousal and alerting functions, sensory gating and directed, selective and sustained attention ([28, 37, 39] see Foster et al. [16] for a review). A number of animal studies have also demonstrated the role of the frontal lobes in attention [22, 30, 40]. It is therefore particularly interesting that frontal lobe dysfunction is also associated with PD, as discussed below.

Traditionally, dysfunction of the complex loop between the caudate nucleus and the prefrontal cortex resulting from striatal dopamine deficiency is presumed to underlie the cognitive deficits of PD. However, depletion of dopamine in the mesocorticolimbic system

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[21], which also projects to the prefrontal cortex, has led some investigators to suggest that it is the degeneration of this system that causes the observed deficits [23, 25]. Moreover, there is dysfunction of non-dopaminergic neurotransmitter pathways innervating the frontal cortex in PD. For example, ascending cholinergic and noradrenergic projections to the frontal cortex are disrupted [1, 13] and altered levels of serotonin in the raphe nuclei have been related to depression and to cognitive deficits in PD [26]. Dysfunction of any one of these major neurotransmitter systems in subcortical-cortical pathways may alter cognitive behaviours that are mediated by the frontal lobes [35].

To examine the changes in attentional function in PD and to determine the relationship between any deficit and a deficit involving the frontal lobes we employed two tasks which permit dissociation between two different aspects of attention: parallel (automatic) processing and serial processing [42]. Treisman and Gelade used two tasks of visual attention. In each task the subject has to identify whether or not a target is present. The task is complicated by the presence of a number of distractors. In the 'simple feature search' condition, the target and distractors have no features in common (for example, the target may be a green T amongst brown Xs). Treisman found that in these circumstances the target appeared to 'pop out' automatically, being identified rapidly and accurately regardless of the number of distractors. In the contrasting 'conjoined feature search' condition, the target and distractors do share one feature (for example the target might be a green T amongst brown Ts and green Xs). In this latter condition the time taken to detect the target typically increases linearly as the number of distractors is increased. Treisman and Gelade interpret the findings on conjunction in terms of their 'feature integration' theory of attention—the subject is required to serially search the stimuli in order to locate and identify the target. If there is a loss of attentional control as a result of a deficit in cognitive processing, reaction times will increase disproportionately as the number of distractors (display complexity) increases in the conjoined feature search condition. The hypothesis which we are advancing concerns the nature of the attentional deficits in PD and whether these impairments may be attributable to the existence of frontal dysfunction. In order to test this hypothesis we examined attentional function in two groups, one with frontal lobe impairment and one without. The hypothesis predicts that there should be a dissociation, with the 'frontally impaired' PD group showing impaired performance on the visual search tasks (relative both to the non-frontally impaired PD group and to the controls), whereas the non-frontally impaired PD group should be unimpaired relative to the controls. Thus, an aim of this study was to specify the precise nature of any attentional deficits in PD, while predicting that any impairment found will only arise in the patient group who have additional frontal lobe dysfunction.

2. Method

2.1. Subjects

Twenty-five right handed subjects with idiopathic PD were recruited from the Movement Disorder clinic of the Royal Hallamshire Hospital, Sheffield, U.K. The group consisted of 15 men and 10 women, whose ages ranged from 42–77 years (mean age = 59, SD = 10). All patients fulfilled the diagnostic criteria of the PD Society, namely: akinesia with rigidity, resting tremor or postural instability, and the absence of clinical signs of other causes of Parkinsonism. None of the subjects had a history of head injury, alcohol abuse or other neurological disorder or medical condition in which central function may become impaired other than PD.

The patients were allocated to one of two groups on the basis of their performance on the Wisconsin Card Sorting Test (WCST). While the WCST is known to be sensitive to frontal lobe dysfunction [19] there has been some controversy surrounding the reliability of the WCST to measure frontal lobe impairment [2, 27]. For instance, Anderson et al. [2] argued that 'the WCST cannot be interpreted in isolation as an indicator of frontal lobe damage'. However, a recent PET study of normal subjects has demonstrated that WCST performance is associated directly with enhanced activation of the dorsolateral prefrontal cortex. In the context of PD, Paolo et al. [31] found that the WCST to be 'sensitive to the subtle executive deficits demonstrated by persons with PD without dementia'.

Performance on the WCST was scored according to the method of Heaton [19]. The 'frontally impaired' group (PD-F) obtained three or fewer categories on the WCST and perseverated to the previous category. In order to increase the likelihood of frontal impairment, it is advisable to adopt a more stringent criterion, namely increased perseverative errors on the WCST, which is claimed to be a relatively sensitive indicator of frontal lobe dysfunction [12, 33].

Consequently we can conclude that PD patients not showing deficits on the WCST are not frontally impaired and secondly that PD patients who show a deficit on the WCST are probably frontally impaired. Subjects were classified as 'frontally impaired' only if they performed poorly on both number of categories achieved and number of perseverative errors. In addition, the 'frontally impaired' group exhibited impaired scores on The Weschler Adult Intelligence Scale Picture Arrangement task ($P < 0.01$) [44], thereby performing poorly on two tests which are sensitive (although not specific) to frontal lobe dysfunction.

The frontally impaired PD group consisted of 12 subjects; 7 women and 5 men, whose ages ranged from 43–73 years (mean age = 62.6, SD = 11.0). The second non-frontally impaired group (PD-NF) all produced five or

more categories on the WCST and made no perseverative errors. This group contained 13 subjects comprising 3 women and 10 men, with an age range of 42–77 years (mean age = 60, SD = 8.7).

There were no significant differences between the two groups on tests of premorbid and current intelligence, as measured by the National Adult Reading Test (NART) [29] ($F(2,32) = 1.592$, ns) and the Wechsler Adult Intelligence Scale Vocabulary Subtest respectively (WAIS Vocab) [44] ($F(1,23) = 0.461$, ns). Both groups were administered the Beck Depression Inventory (BDI) [3] and the Blessed Dementia Scale (BDS) [4]; there were no significant differences between the groups and no depression or dementia was found based on these scales ($F(1,23) = 0.1.257$, ns), ($F(1,23) = 0.241$, ns), respectively. There was no significant difference between the two patient groups on three motor measures: Kings College Rating Scale (KCRS) [6] ($F(1,23) = 0.920$, ns), the motor score on the Unified Parkinson's Disease Rating Scale (UPDRS) [14] ($F(2,32) = 1.592$, ns) and the Fine Finger Movements test (FFM) [9] ($F(1,23) = 0.2.648$, ns), in which the subject is asked to rotate a spindle between thumb and forefinger as quickly as possible for 30 s. The groups did not differ in the duration of the disease. Mean performance and SD on these tests are shown in Table 1.

Seventeen PD subjects were treated with a levodopa preparation (Madopar (15) Sinemet (2)), four were taking dopamine agonists (bromocriptine (1), pergolide (2), lysuride (1)) and two subjects were on an anticholinergic preparation (benzhexol). Two of the patients were untreated.

A control group of age matched healthy subjects (Controls) was drawn from members of Age Concern in Sheffield, U.K. There were 10 subjects, 8 female and 2 male, whose ages ranged from 52–69 years (mean age = 62.6, SD = 5.02). None of the subjects performed abnormally on the Blessed Dementia Scale (mean = 2, SD = 2). NART score for this group was not significantly different from either of the two PD groups (mean = 113.4, SD = 9) ($F(2,32) = 0.531$, ns).

3. Materials

3.1. The experimental tasks

Subjects completed two visual search tasks based on those by Treisman and Gelade [42]. Subjects were required to detect the presence of a target and to withhold the response on target absent trials. The experiment comprised two conditions; simple feature search and conjoined feature search. In each condition there were five blocks of 32 trials. Half of each block of trials contained target present trials and the remaining half were target absent. For both present and absent trials, 0, 3, 6 or 12 distractors appeared with equal probability. Stimulus presentation order within each block was randomised. On target present trials, the target was equally likely to appear in each quadrant of the screen. All subjects were tested on an Apple Macintosh computer. In the simple feature search condition, the target differed from the distractors by only one feature. The target was a small shaded circle. The distractors were unshaded circles of the same size. Target and distractors had a black outline. In the conjoined feature search condition, the target was the same as the simple feature search condition but the distractors were either unshaded circles, or shaded squares. Consequently the target was defined by a conjunction of separate properties of the distractors (i.e. the target was uniquely specified by the combination of being both shaded and a circle). For all subjects the simple feature search task was administered first.

4. Procedure

Subjects had been preselected on the basis of their psychometric test performance, taken within the previous six months prior to this experiment as part of a longitudinal study within the department (Table 1). Subjects were asked to sit directly in front of the computer at a distance that was comfortable to them. They were told

Table 1
Performance of the two groups on criterion and psychometric tests

	WCST		WAIS P.A.	NART	BDS	WAIS Vocab.	BDI	KCRS	UPDRS	Duration
	Categories	Perseveration								
Frontal	1.0	30.3 (6.6)	6.75 (2)	110.3 (10)	2.25 (2)	12.54 (2.5)	8.16 (4)	19.0 (12.5)	23.0 (13)	4.1 (1.83)
Non-frontal	8.25	11.4 (5.1)	9.46 (3)	109.5 (9)	2.45 (3)	13.07 (2.5)	10.61 (6)	15.0 (7.0)	15.0 (8.0)	4.2 (1.4)

WCST, Wisconsin Card Sorting Test; WAIS P.A., Weschler Adult Intelligence Scale (Picture Arrangement); NART, National Adult Reading Test; BDS, Blessed Dementia Scale; WAIS Vocab, Weschler Adult Intelligence Scale (Vocabulary Test); BDI, Beck Depression Inventory; KCRS, Kings College Rating Scale; UPDRS, Unified Parkinson's Disease Rating Scale.

to rest their right hand lightly on the space bar of the computer keyboard. Subjects were instructed to respond only when they detected the target and to do so as quickly as possible. They were then given a practice run of four trials during which time further explanation was provided when necessary. No explicit feedback was given, but the score was shown in the bottom right hand corner of the screen during the testing phase. This score showed two figures; one which gave the number of trials presented, and another which showed the number of correct responses. Errors could be either omissions or commissions. Subjects took short breaks between blocks. The test session took approximately 45 min.

5. Results

5.1. Errors of omission and commission

No omission errors were made by any of the subjects. In addition, no more than two errors of commission were made by any subject and the mean error rates did not differ significantly between groups ($F(2,137) = 2.06$, ns).

5.2. Reaction times

It may be seen from Figs 3 and 4 that the pattern of results in both conditions is as Treisman predicted. There was no increase in reaction times as the numbers of distractors increased in the simple feature search condition, whereas in the conjoined feature search condition the reaction times increased proportionally as the number of alternatives increased. Interestingly, this normal pattern of results occurs for all three subject groups. The pattern of reaction time performance across trials was analysed using a 2-Factor analysis of variance of group (PD-F, PD-NF, Controls) by condition (simple feature search, conjoined feature search). The analysis showed significant main effects of group and condition ($F(2,32) = 6.2$, $P < 0.01$; $F(1,32) = 356.5$, $P < 0.0001$ respectively) and a significant interaction between group and condition ($F(2,32) = 3.64$, $P < 0.05$). Graph means indicated that the interaction between group and condition was due to an increase in the reaction time of the control subjects on the 12 array size only in the simple feature search, relative to the two patient groups. The reaction times of the control group fell between the two patient groups in this condition. Post hoc analysis indicated that the PD-F group had significantly slower reaction times on both conditions than either the PD-NF group or the controls ($P < 0.01$). There was no significant difference between the PD-NF group and the controls ($P > 0.05$). For all the subject groups, the conjoined feature search condition produced significantly slower reaction times overall than the simple feature search condition ($P < 0.001$).

A 1-Factor analysis of variance of group means (PD-

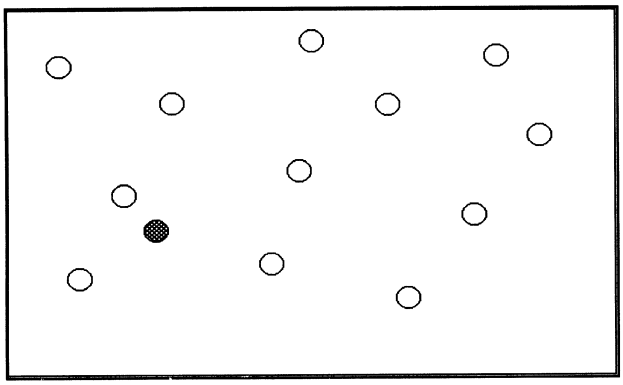

Fig. 1. Example screen display for the simple feature search condition.

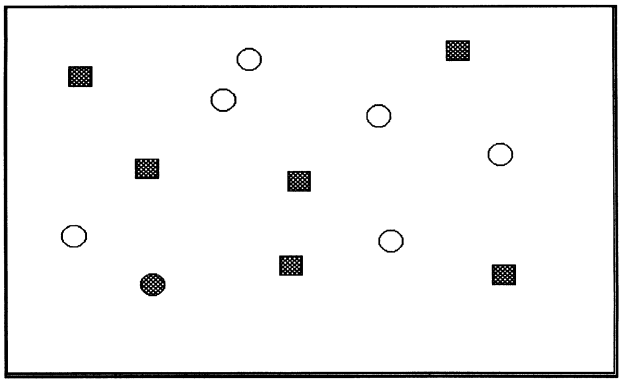

Fig. 2. Example screen display for the conjoined feature search condition.

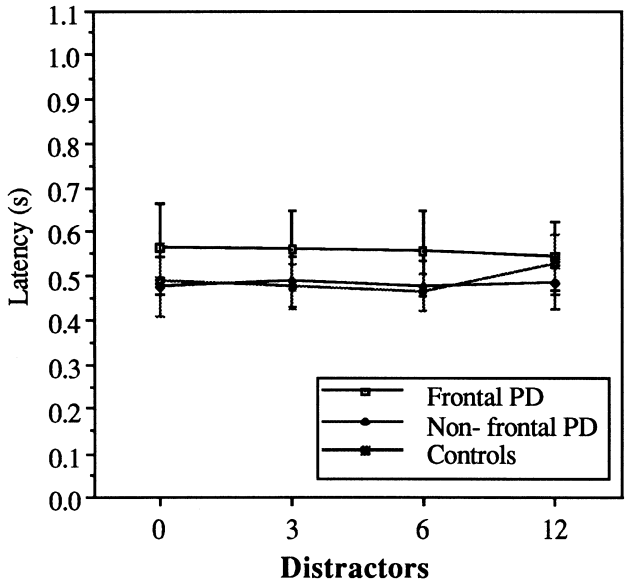

Fig. 3. Latencies for the simple feature search condition. Mean reaction times and standard deviation for each of the three subject groups with 0, 3, 6 and 12 distractors appearing with the target. In this condition reaction times do not increase as the number of distractors increase.

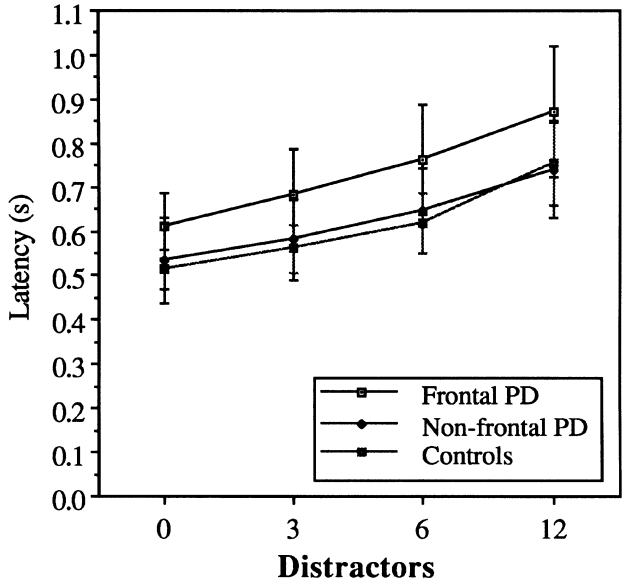

Fig. 4. Latencies for the conjoined feature search condition. Mean reaction times and standard deviation for each of the three subject groups with 0, 3, 6 and 12 distractors appearing with the target. The greater the number of distractors, the slower the reaction time as the subject serially searches the screen.

F, PD-NF, controls) was carried out for each condition separately.

In the simple feature search condition there was a significant effect of group ($F(2,32) = 4.80$, $P < 0.05$). The PD-F group had significantly slower reaction times than the PD-NF group, or the Controls ($F(1,23) = 7.41$, $P < 0.05$; $F(1,20) = 4.96$, $P < 0.05$; respectively). There was no significant difference in reaction times between the PD-NF and the Control group ($F(1,21) = 0.269$, ns). In the conjoined feature search condition there was a significant effect of group ($F(2,32) = 6.59$, $P < 0.01$). As in the previous condition, the PD-F group showed significantly slower reaction times than the PD-NF group ($F(1,23) = 7.67$. $P < 0.05$] and the Control group ($F(1,20) = 10.88$, $P < 0.01$). Again, there was no significant difference between the PD-NF group and the Controls ($F(1,21) = 0.014$, ns).

5.3. Intercept and Slope

It may be seen from Figs 3 and 4 that the data for all groups follow the expected pattern. In the simple feature search condition there is little or no change in latency as the number of distractors increases, whereas there is the expected linear increase in latency with number of distractors in the conjoined feature search condition. It is therefore appropriate to perform a linear regression on the data; a procedure which determines the intercept and the slope of the best fit straight line through the four points. It is quite possible that PD may affect the slope or the intercept or both.[1] A greater slope would suggest a reduced rate of information processing (an effect of executive control), while a higher intercept would indicate a general psychomotor slowing independent of complexity, possibly implicating a general deficit in arousal/vigilance. An analysis of variance was then performed on the intercept and slope separately. Mean values for slope and intercept for each experimental condition are given in Table 2.

5.4. Results for the intercept

An overall 2-Factor Analysis of Variance of group (PD-F, PD-NF, Controls) and condition (simple feature search, conjoined feature search), was undertaken. There was a significant effect of group ($F(2,32) = 3.2$, $P < 0.05$). The PD-F group were slower than either the PD-NF group or the Controls. There was no significant effect of condition ($F(1,32) = 3.4$, ns) or of group by condition ($F(2,32) = 0.32$, ns). Further analyses using a 1 Factor Analysis of Variance of group (PD-F, PD-NF, Controls) separately for each condition revealed a highly significant effect of group on the conjoined feature search condition ($F(2,32) = 6.5$, $P < 0.01$). The PD-NF and the control subjects sustained faster reaction times than the PD-F group in this condition. There was no significant effect of group in the simple feature search condition ($F(2,32) = 1.50$, ns).

In a further analysis, an overall 2-Factor Analysis of Variance of group (PD-F, PD-NF) and condition (simple feature search, conjoined feature search), was carried out on the PD groups alone. Results revealed a significant effect of group and of condition ($F(1,23) = 6.8$, $P < 0.05$; $F(1,23) = 35.22$, $P < 0.001$ respectively). The PD-NF showed faster reaction times than the PD-F group. For both groups, the conjoined feature search produced slower reaction times overall than the simple feature search condition. Again, there was no significant interaction between group and condition ($F(1,23) = 0.01$, ns). Closer analysis of main effects revealed a significant effect of group on both the simple ($F(1,23) = 6.6$, $P < 0.05$) and conjoined ($F(1,23) = 6.1$, $P < 0.05$) condition. In both conditions, the PD-NF subjects produced faster reaction times than the PD-F group. Inspection of the data for the simple feature search condition indicated that the

[1] Unfortunately, slope and intercept co-vary, and therefore in order to analyse the performance for slope and intercept separately, the centroid of each individual's four data points was calculated. The centroid is the most reliable summary statistic for the overall data, and the regression line will always travel through it. Independent estimates of intercept and slope may be obtained by evaluating the intercept by projecting backwards a line from the individual centroid with slope equal to population mean, and second calculating the slope of the line from the individual's centroid to the population mean intercept. These represent the most robust, unbiased estimates for the intercept and slope respectively.

Table 2
Mean and SD for the intercept and slope

	Simple feature search		Conjoined feature search	
	Intercept (s)	Slope (s/distractor)	Intercept (s)	Slope (s/distractor)
Frontal	0.558	−0.001	0.61	0.022
	(0.104)	(0.005)	(0.09)	(0.01)
Non-frontal	0.486	0	0.541	0.02
	(0.062)	(0.002)	(0.092)	(0.005)
Controls	0.506	0.002	0.528	0.021
	(0.046)	(0.006)	(0.179)	(0.006)

reason for the discrepancy between the two-group data here and the three-group data above was that the control group performance lay between the two PD groups (for the 12 array size only).

Finally, a 2-Factor Analysis of Variance was carried out on the PD-NF and Controls group alone. There was no significant difference between the groups, or conditions ($F(1,21) = 0.10$, ns; $F(1,21) = 0.35$, ns respectively). There was no interaction between group and condition ($F(1,21) = 2.11$, ns).

5.5. Results for the slope

An overall 2-Factor Analysis of Variance of group (PD-F, PD-NF, Controls) and condition (simple feature search, conjoined feature search) indicated that there was no overall significant effect of group ($F(2,31) = 1.00$, ns). There was a highly significant effect of condition ($F(1,31) = 158.34$, $P < 0.0001$). It appears that for all groups, slopes were significantly higher on the conjoined feature search condition. There was no interaction between group and condition ($F(2,32) = 1.30$, ns).

In a further analysis, an overall 2-Factor Analysis of Variance of group (PD-F, PD-NF) and condition (simple feature search, conjoined feature search), was carried out on the PD groups alone. Results revealed no significant effect of group ($F(1,23) = 1.12$, ns) but a highly significant effect of condition ($F(1,21) = 105.82$, $P < 0.0001$). For both groups, slopes were significantly higher on the conjoined feature search condition. There was no interaction between group and condition ($F(1,23) = 2.27$, ns).

Finally, a 2-Factor Analysis of Variance was carried out on the PD-NF and Controls group alone. There was no significant effect of group but a highly significant effect of condition. ($F(1,20) = 1.948$, ns; $F(1,20) = 202.95$, $P < 0.0001$). Again, for both groups, slopes were significantly higher on the conjoined feature search condition. There was no interaction between group and condition ($F(1,20) = 0.34$, ns).

6. Discussion

The results of the visual search tasks produced three main findings. First, in the simple feature search condition, the reaction times of both the PD groups and the control group remained at a constant level regardless of the number of distractors presented, indicating that their parallel processing was intact (and that the target did indeed 'pop out' as Treisman and Gelade predict); second, in the conjoined feature search condition there were no differences between the groups in the effects of task complexity (slope of the regression line). This indicates that there was no information processing deficit in PD due to an increase in cognitive complexity on this task. Third, baseline speed of response (the intercept) was significantly slower in both conditions for the 'frontally impaired' group but not for the non-frontally impaired group compared with controls. Before interpreting these findings, however, it is important to assess the extent to which the reduced baseline response speed might be attributable to motor output limitations specific to the 'frontally impaired' PD group.

If poor performance is related to bradykinesia then there should be a positive correlation between motor ratings and reaction times. A correlation analysis was undertaken to assess this possibility. There was no significant difference between the 'frontally impaired' and non-frontally impaired PD groups in their motor ratings ($F(1,20) = 3.83$, ns), and for both groups only a small non-significant correlation between these ratings and reaction times on the task ($r = 0.20$). However there was a significant correlation ($r = 0.30$) between fine finger movement (FFM) scores and baseline reaction times on this task for both PD groups. Nonetheless, the non-frontally impaired group, who are by definition motor-impaired (and to the same degree as the 'frontally impaired' group), produced reaction times that were no slower than those of the control subjects who have no motor dysfunction. This is critical, because it suggests that the type of motor disability characterised by PD does not sig-

nificantly impair the ability to carry out this task. However, since there was a correlation between FFM scores and baseline reaction times for both PD groups we explored the possibility of defective motor control further by taking into account the specific nature of the movement required to complete the task effectively. The experimental task undertaken involved the single depression of a finger in order to move the space bar. This movement is similar to the 'Finger Taps' rating on the UPDRS and KCRS, and for this reason, the finger taps scores for each PD subject was analysed separately. There was no significant difference between the groups on this single score, nor did the ratings correlate significantly with reaction times ($r = 0.1$). Finally, an analysis of covariance was undertaken for all of the subject groups, with the finger taps as the covariate. This analysis still resulted in a significant difference between groups on the intercept ($F(1,21) = 8.0$, $P < 0.01$, $F(1,21) = 4.5$, $P < 0.05$; simple feature search and conjoined feature search respectively). Overall, therefore, there was no significant difference between the two PD groups in motor ratings, and no correlation between motor ratings in the two PD groups and experimental results on the intercept or slope for either condition. We can conclude therefore that the baseline differences in speed between the two Parkinson's groups are not caused directly by motor skill deficits.

The performance of the non-frontally impaired group was equivalent to that of the control subjects. By contrast, the baseline performance of the 'frontally impaired' group was impaired relative to the other two groups, though on the conjoined feature task the increase in reaction time as the number of targets increased was normal. In other words, taken as a group, the 'frontally impaired' patients were not disproportionally slowed compared to the non-frontally impaired PD group as the array size increased. Therefore, while no central processing deficit appears to exist, the patients exhibit a constant slowing of response speed in an otherwise intact performance. The impairment is simple, absolute and independent of the cognitive complexity of the task and may represent a non-specific global impairment. There are strong grounds to believe that the 'frontally impaired' patients do indeed suffer from frontal dysfunction, as reflected by their poor performance on the WCST generally and specifically on perseverative errors (see Method for a fuller discussion). The results therefore suggest that the frontal lobes may be critical in slowed response latencies in Parkinson's disease.

The results of this study are consistent with our prediction that impairment on this task would only ensue for the 'frontally impaired' group, thus implicating the frontal lobes in the pathology of cognitive dysfunction in PD. However, according to Treisman's theory, the impairment is not one of attention per se, since the efficiency of central cognitive processes required to carry out the task are no different from the controls in this group. The angle of the slope on the conjoined feature task did not increase disproportionally as the number of distractors increased in this frontally impaired group which suggests that the deficit observed is independent of the processes that require selective attention. This result is compatible with that of previous studies examining PD populations. The intercept, which is a reaction time corresponding to the detection of a target with no alternatives (distractors), is equivalent to a simple reaction time paradigm. As such, our results gain direct support from research undertaken by Jordan et al. [24]. In this study, a group of PD patients and control subjects were examined on simple reaction time (SRT) in which subjects consistently respond in the same way regardless of the stimulus; and on go/no-go choice reaction time (CRT), where the response is different depending upon the nature of the stimulus. Results revealed a prolongation of SRT which correlated with the number of perseverative responses on the Wisconsin Card Sorting Test. The authors suggest that these results indicate that frontal lobe function may be a critical influence in the genesis of slowed response speed in PD. In an interesting study by Goodrich et al. [18], control subjects were relatively more impaired than a PD group on an SRT task by the imposition of a secondary oral reading task, effectively abolishing the usual SRT deficit attributed to PD patients.

Goodrich et al. propose that their results can be attributed to evidence of an attentional demanding process that confers speed on the control group's SRT, but which cannot be utilised under dual task conditions. Particularly pertinent to our research was the suggestion that in PD there is an impairment in this attention demanding process which does not allow them to use it under normal SRT conditions.

In summary, the PD group who had no frontal impairment performed as well as the controls on all aspects of the visual search tasks. The PD group with frontal dysfunction showed significant slowing of global baseline response speed (but no differential slowing as a function of number of distractors). The data are consistent with the hypothesis that cognitive dysfunction affecting response speed may ensue only for a subgroup of PD patients for whom the pathophysiology also affects the frontal lobes.

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