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Fractionation of visuoperceptual dysfunction in Parkinson's disease

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Abstract

There is considerable evidence that visuoperceptual function is impaired in Parkinson's disease although this view remains contentious. The issue is confounded by studies which have demonstrated impairment of visual sensation, in particular high-contrast visual acuity, in Parkinson's disease. We have measured the visuoperceptual performance of 16 patients with mild to moderate Parkinson's disease, both on and off drugs, and 16 age and sex matched control subjects on non-motor tests of visual resolution, static perception, and dynamic perception. Performance on the perceptual tasks was measured in terms of perceptual resolutions and was found impaired in the parkinsonian group. After removal of the contribution of poorer visual resolution, the overall visual perception remained impaired, although to a relatively subtle degree, such that the difference between the two groups on its static and dynamic components did not reach significance.

Keywords: Visual perception; Visual acuity; Visuospatial deficits; Performance fractionation; Parkinson's disease

1. Introduction

There is considerable evidence that visuoperceptual function is impaired in Parkinson's disease (PD) (Boller et al., 1984; Ransmayr et al., 1987; Blonder et al., 1989; Bradley et al., 1989; Netherton et al., 1989; Mohr et al., 1990a,b; Raskin et al., 1990; Levin et al., 1991; Testa et al., 1993) although this view remains contentious with lack of confirmation from other studies (Brown and Marsden, 1986; Sala et al., 1986; Girotti et al., 1988; Levin et al., 1989; Stelmach et al., 1989; Cooper et al., 1991; Daum and Quinn, 1991; Wilson et al., 1992; Richards et al., 1993). Visual sensation has also been demonstrated impaired in PD in terms of contrast sensitivity (Bulens et al., 1986,1988; Skrandies and Gottlob, 1986; Bodis-Wollner et al., 1987; Regan and Maxner, 1987), low-contrast visual acuity (Regan and Maxner, 1987), and high-contrast visual acuity (Jones et al., 1992).

The real or apparent presence of visual (i.e., visuosensory and visuoperceptual) deficits in PD raises two questions. First, could the relatively small deficits seen on visuoperceptual tests simply be due to the motor response inherent in the majority of the tests of visuoperceptual function used (Boller et al., 1984; Girotti et al., 1988; Stelmach et al., 1989)? For example, Stelmach et al. (1989) noted that of 19 studies of visuoperceptual function in Parkinson's disease, 9 were based on responses involving a substantial motor component. Interestingly *all* of these latter studies reported impaired visuoperceptual abilities, compared with only three of the remaining 10 studies in which the visuoperceptual task had only a trivial or no motor component. Second, could the visuoperceptual deficits be due to impaired visual acuity?

Two studies have addressed the first question by using reaction time tasks in conjunction with stimuli of varying perceptual complexity to study visuoperceptual function in PD. Stelmach et al. (1989) had subjects press one of two response keys according to which of two stimuli, presented simultaneously on the right and left of a screen, deviated vertically from a horizontal mid-line. From analysis of the differential in reaction times between small and large deviations, they concluded that perceptual judgement is not impaired in Parkinson's disease. Similarly, Daum and Quinn (1991)

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used reaction time tasks to show that there was no disproportionate increase in response initiation times between a nonspatial condition and more complex visuospatial conditions in subjects with PD. They concluded that their results did not support the presence of a generalized visuospatial deficit in PD.

Analysis of covariance has also been used to separate the perceptual and motor components of responses to perceptual-motor tasks. By this means, Girotti et al. (1988) found there was no difference between parkinsonian patients and controls in test scores on visuoperceptual and perceptual-motor tasks when adjusted for reaction and movement times. They concluded that their results "stress the main role of motor dysfunction in visuospatial and perceptual motor impairment" in PD.

The present paper addresses both of the above questions. It describes three non-motor tests of visual function – visual resolution, static perception, and dynamic perception – and an analytical technique whereby the contribution of visual acuity to visuoperceptual function can be removed. These are then applied in a study of visuoperceptual performance in PD.

2. Methods

Subjects

The experimental group comprised 16 patients with relatively mild idiopathic PD made up of 9 males and 7 females. Ages ranged from 38 to 72 years (mean 57.2 years). All were within grades I–III on the Hoehn-Yahr scale (Hoehn and Yahr, 1967) (2 on I, 5 on II, 9 on III), were not suffering from "on–off", had no dyskinesia, and no other neurologic history. They were recruited from a hospital neurology outpatient clinic and the duration of illness ranged from 0.4 to 12 years (mean 5.5 years). All patients were being treated with either L-dopa plus a decarboxylase inhibitor (6) or an anticholinergic (7) or both (3), and these were supplemented in some patients by either bromocriptine (1) or amantidine (4). Patients (and controls) were included only if they had a corrected visual acuity of 6/9 or better in one eye, no visual field defect, and normal ophthalmoscopic findings. All appeared mentally normal on full neurological evaluation which included clinical measures of orientation and memory.

The control group comprised 16 subjects who had no neurological symptoms or history. They were matched against the PD group (using a paired experimental design) for age (range 38–74 years, mean 57.7 years, NS) and sex.

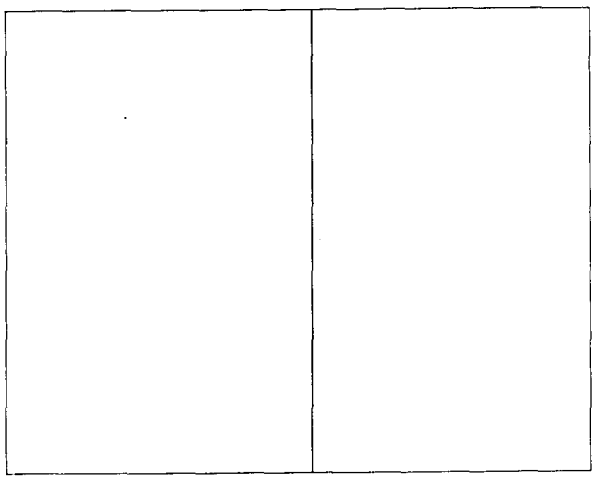

Fig. 1. Visual display for the visual resolution test.

Apparatus

The system hardware comprised a PDP-11/34 computer [1] with a VT11 dynamic vector graphics system (1024 × 1024 resolution, 279 × 228 mm screen) for displaying test stimuli (eye-screen distance 132 cm). Tests were generated and analyzed by software written in FORTRAN IV [1], except for display of moving stimuli in the dynamic perception task for which the faster MACRO assembly language was necessary.

Tests

A non-paced verbal response was required by all four visuoperceptual tests, thus eliminating any possible confounding effects due to motor deficits.

Visual acuity. Corrected visual acuity for each eye was measured on a Snellen chart at 6 m (see also Jones et al., 1992). The best eye result was used in the present study.

Visual resolution. This test measured a subject's ability to identify the position of a dot with respect to a vertical line on the graphics screen (Fig. 1). Dot-line separations were in multiples of 0.27 mm (i.e., pixels in horizontal plane) and the test contained 20 trials comprising two at 10 pixels and three at each separation from 5 down to 0 pixels. Visual resolution was defined as the minimum separation at which and beyond a subject was always able to correctly identify the dot as being off the centre of the line (see also Jones et al., 1992).

[1] Since the study, the sensory-motor test battery (including performance fractionation procedures) has been redeveloped in Turbo Pascal to run on a 386/486 PC-based system (Jones et al., 1993).

Table 1
Description of the 20 trials in static perception test

Trial	Waveform		Arrow position		
	Type	Phase (deg) [a]	Offset [b] (pixels) [d]	Direction	Spacing [c] (pixels) [d]
1	Vertical line	–	6	L	6.00
2	Vertical line	–	16	R	16.00
3	Vertical line	–	0	–	0
4	Vertical line	–	3	R	3.00
5	Sine-wave	180	15	L	5.13
6	Sine-wave	180	0	–	0
7	Sine-wave	90	10	R	10.00
8	Sine-wave	120	0	–	0
9	Sine-wave	60	6	R	3.29
10	Sine-wave	−90	10	R	10.00
11	Sine-wave	−90	0	–	0
12	Sine-wave	60	8	L	4.38
13	Sine-wave	120	10	R	6.33
14	Sine-wave	-90	4	L	4.00
15	Sine-wave	0	15	L	4.78
16	Sine-wave	60	0	–	0
17	Sine-wave	90	6	L	5.74
18	Sine-wave	120	6	R	3.80
19	Sine-wave	180	10	R	3.11
20	Sine-wave	0	10	R	3.42

[a] The phase of the waveform indicates the position on the sine-wave at which the point of the arrow is placed or offset, e.g., The sine-wave is shown at 0 deg in Fig. 2, whereas a 90 deg phase would refer to the right-most peak (i.e., sine-wave dropped by 90 deg).
[b] Offset of arrow from waveform is in the horizontal plane.
[c] Spacing is defined as closest distance between point of arrow and the vectors making up the target waveform (see Fig. 4).
[d] Throughout paper, distances on screen are in terms of pixels in the screen's horizontal plane, where 1 pixel = 0.273 mm.

Table 2
Description of the 20 trials in dynamic perception test

Trial	Duration (s)	Auto-tracking error			
		Type	Offset (pixels)	Disjointed sections [a]	Max spacing [b] (pixels)
1	10	Zero	–	None	–
2	10	Left-shift	8	None	8.00
3	10	Right-shift	8	Disjoint #1	8.00
4	10	Zero	–	None	–
5	10	Lag	8 (70 ms)	None	6.15
6	5	Lead	8 (70 ms)	None	6.27
7	5	Zero	–	None	–
8	5	Sine [c]	8	None	7.00
9	5	Left-shift	4	None	4.00
10	5	Right-shift	6	Disjoint #2	5.74
11	5	Zero	–	None	–
12	5	Lag	8 (70 ms)	None	5.93
13	2	Right-shift	8	None	7.65
14	2	Zero	–	None	–
15	2	Lag	8 (70 ms)	None	6.27
16	2	Left-shift	6	Disjoint #3	6.00
17	2	Sine [c]	8	None	7.00
18	2	Zero	–	None	–
19	2	Lead	8 (70 ms)	Disjoint #4	6.22
20	2	Sine [c]	6	None	4.78

[a] Disjointed errors (i.e., auto-tracking errors present for only part(s) of a trial) were as follows: Disjoint #1 = On–40%, Off–20%, On–40%; Disjoint #2 = On–20%, Off–40%, On–40%; Disjoint #3 = On–50%, Off–50%; Disjoint #4 = Off–50%, On–50%. Sharp transitions between on- and off-line sections (which would otherwise produce an undesired tell-tale jump) were eliminated through the use of smooth transitions.
[b] Maximum spacing is defined as the largest spacing (see [c] in Table 1) occurring during a trial.
[c] All sinusoidal auto-tracking errors had a frequency of 0.45 Hz.

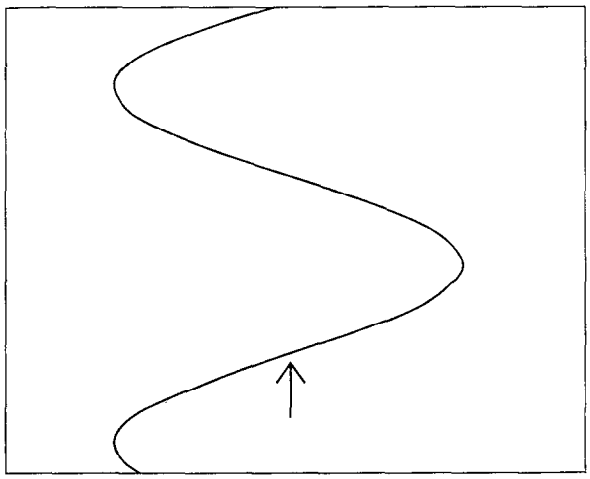

Fig. 2. Visual display for the static perception test.

Static perception. This test measured a subject's ability to perceive whether the point of the arrow was on or off a static vertical line in 4 trials and a static sine-wave in 16 trials (Table 1). The test score was the number of incorrect responses over the 20 trials. The sine-wave was vertically orientated, comprised 1.23 cycles, and had a horizontal range on screen of 170 mm (Fig. 2); the arrow's shaft was 14.3 mm long and the sides of the arrow-head were 5.6 mm long and at 51 deg to the shaft.

Dynamic perception. This test measured a subject's ability to determine whether a computer-controlled arrow point stayed perfectly on a preview random target signal as it moved down the screen (Fig. 3). The duration of the 20 trials decreased from 10 to 2 s and various error offsets were simulated (Table 2). The test score was defined similar to that of static perception. The random target had a bandwidth of 0.21 Hz, a rate of descent of 25.0 mm/s, preview and postview times

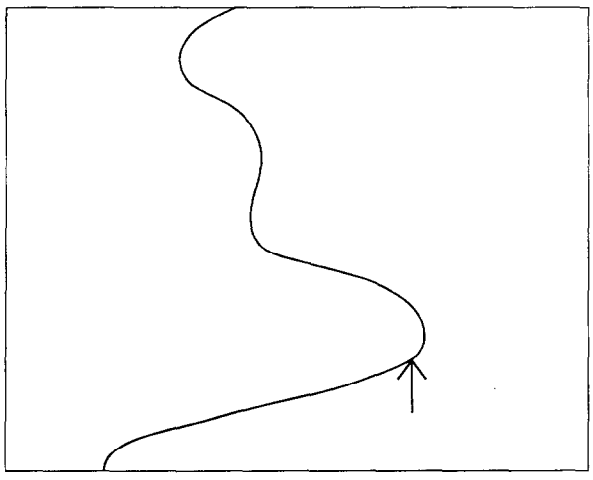

Fig. 3. Visual display for the dynamic perception test.

of 8.0 s and 1.1 s respectively, and a horizontal range on screen of 170 mm; the arrow was identical to that in the static perception task.

In addition to the four visuoperceptual tests, an informal arrow perception/comprehension task was undertaken after the visual resolution test. This involved a large bright dot placed at 13 positions on or around various parts of an arrow identical to that used in the static and dynamic perceptual tests. Subjects were required to indicate whether or not the dot was exactly on the point of the arrow and the task was repeated until all responses were correct. In this way, the assessor could be satisfied that the subject fully understood what was meant by the "point of the arrow" before moving on to the visuoperceptual tests in which the arrow was a central feature.

Fractionation of visuoperceptual performance

A central feature of the performance analysis was the ability to define and remove the influence of successively more complex tests from one another; that is, visual resolution from static perception, static from dynamic perception, and visual resolution from dynamic perception.

To estimate the proportion of incorrect responses on the static perception test which could be attributed to limitations in visual acuity or resolution, it was first necessary to translate the ordinal score of incorrect responses into a quantitative measure of, what we have termed, static perception resolution. For each trial the closest distance between the point of the arrow and the straight line segments making up the target waveform on the screen, i.e., the spacing, was calculated (Fig. 4). The perceptual resolution for a subject is then defined as the minimum spacing over the 20 trials at and beyond which the subject was always able to resolve or perceive the arrow as being off the target. It was then simply a matter of subtracting a subject's visual resolution from static perception resolution to gain a measure of the subject's static perception function alone.

A similar process was applied to data from the dynamic perception test. The spacing between the point of the arrow and the target was calculated at each screen update (35 ms interval) as the target random-wave moved down the screen and the maximum spacing during each trial derived (Fig. 5). The dynamic perception resolution (DPR) was then defined as the minimum of maximum spacings over the 20 trials at and beyond which a subject was always able to perceive the arrow as being off the target at some stage during its descent. Subtracting visual resolution from DPR thus gives a measure of a subject's dynamic perception function without contamination due to visual shortcomings of a purely sensory or optical nature. Likewise, subtraction of static perception resolution from dynamic perception resolution provides a measure of

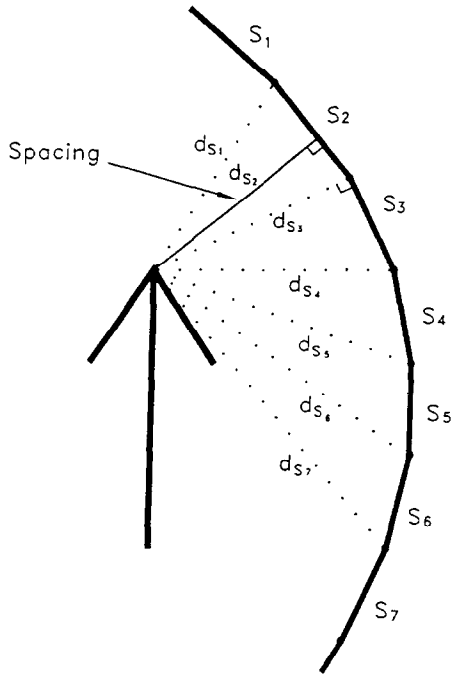

Fig. 4. Close-up of the static perception test showing the shortest distances (d_{S1} ... d_{Sm}) between the point of the arrow and the straight-line segments (S_1 ... S_m) making up the sine-wave. The *spacing* is the minimum of these distances.

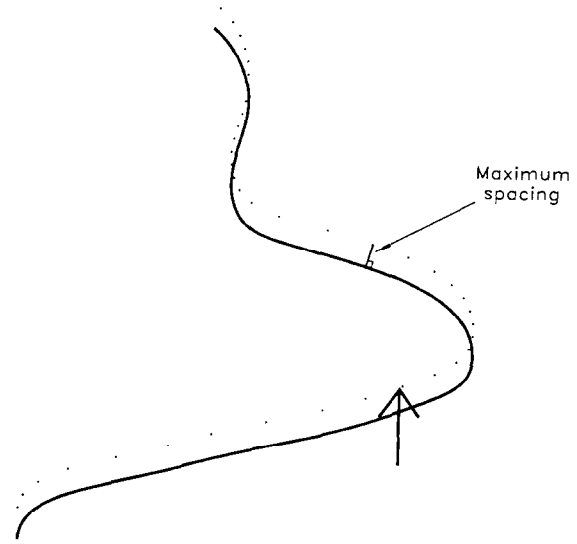

Fig. 5. A snap-shot of the dynamic perception test showing the maximum spacing for this trial. In this example, the arrow automatically followed the descending target with a constant lag (the dots indicating the arrow's trajectory were not displayed during the actual task).

perceptual functioning solely relating to the non-stationary nature of a visual stimulus.

Experimental procedure

Subjects were assessed on two sessions, one week apart. The patients were on their normal drug regime for one session and off their anti-parkinsonian medication for 24 h on the other session.

The 16 patients and their matched controls were evenly allocated to two subgroups in a randomized cross-over design designed to eliminate any between-session order effects (primarily learning) in determination of the effect of medication (on vs off drugs) on performance.

Data analysis

The non-parametric Wilcoxon matched-pairs statistic was used for both between-group and within-subject comparisons, due to its greater robustness over its parametric paired *t*-test equivalent, with only minimal loss of power. This is important with several variables being inherently non-quantitative and many quantitative variables having skewed distributions as well as different variances between normal and patient groups.

3. Results

On versus off drugs

No difference was found in performance between on-drugs and off-drugs on any of the visuoperceptual measures. Consequently, the following results represent averaged data from the on-drug and off-drug sessions for all subjects.

Visuoperceptual functions

The Parkinsonian subjects were impaired on both visual acuity tests (i.e., Snellen and resolution) and, even more so, on the two visuoperceptual tests (Table

Table 3
Performance on visuoperceptual tests

Function		PD	Normal	Difference (%)	p
Visual acuity (Snellen)	(moa)	1.10 (6/6.58)	0.88 (6/5.25)	25	**
Visual resolution	(moa)	2.08	1.68	24	**
Static perception	(incorrect)	2.53	0.69	267	**
Dynamic perception	(incorrect)	4.87	2.19	122	**

moa = minutes of arc. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4
Visuoperceptual resolutions (pixels) transformed from raw scores of incorrect responses

sTest/function		PD	Normal	Difference	p
Raw scores					
Visual resolution	(VR)	2.94	2.37	0.56 (24%)	**
		↕ ***	↕ ***		
Static perception	(SPR)	4.48	3.38	1.10 (33%)	***
		↕ ***	↕ ***		
Dynamic perception	(DPR)	6.76	5.30	1.46 (27%)	***
Primitive-corrected scores					
Static perception	(SPR-VR)	1.54	1.00	0.54 (54%)	–
Dynamic perception	(DPR-SPR)	2.28	1.92	0.36 (19%)	–
Total perception	(DPR-VR)	3.82	2.92	0.90 (31%)	*

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

3). In preparation for removal of the acuity component from the perceptual tests, scores from the latter were converted from number of incorrect responses to perceptual resolutions (Table 4). The PD group remained impaired on the static and dynamic perception tests at 33% and 27% respectively. Confirmation of an expected progression in visuoperceptual complexity between the three tasks was also seen with the increase in magnitudes of the resolutions in going from visual resolution to static perception (52% and 43% in the PD and control groups respectively), and from static perception to dynamic perception (51% and 57%).

With comparable measures of performance for the three tests (i.e., visuoperceptual resolutions in screen pixels), the contribution of the primary feature in each test to the resolution measured on that test could be calculated simply by subtracting off the resolution of the more basic visuoperception function (Table 4). Having removed the effect of differences in visual acuity between the two groups, the overall visual perception function (i.e., dynamic minus visual resolution) remained impaired in the PD subjects (31%). Conversely, although both the static and dynamic elements making up the total perception tended to be worse in the PD group when corrected for the more basic function (54% and 19% respectively), the differences, by themselves, did not reach significance.

4. Discussion

We have presented tests for measurement of visual resolution, static visual perception, and dynamic visual perception. Application of these has allowed us to confirm results from several previous studies that visuoperceptual performance in impaired in PD (Boller et al., 1984; Ransmayr et al., 1987; Blonder et al., 1989; Bradley et al., 1989; Netherton et al., 1989; Mohr et al., 1990a, Mohr et al., 1990b; Raskin et al., 1990; Levin et al., 1991; Testa et al., 1993).

The primary purpose of this paper has, however, been 2-fold. First, the description of techniques which allow quantification and fractionation of several elements of visuoperception; the concept of a visuoperceptual buffer zone around a target is central to these procedures and allows separation of the perceptual component of performance on visuoperceptual tasks from the more primitive visual acuity component. Second, the application of these techniques to determination of whether apparent deficits of visuoperceptual performance in our and the above studies could be explained by impaired motor performance or reduced visual acuity.

Application of the fractionation techniques has led to this being the first study to demonstrate that visual perception is impaired in PD after taking impaired visual acuity into account. Nevertheless, although overall visual perception was substantially impaired in the PD group (31%), it only just reached statistical significance ($p = 0.028$). This appears to reflect a wide disparity of perceptual deficits in PD with some subjects being severely affected while others remain effectively unimpaired. This, in turn, may reflect a low correlation between levels and progression of motor sequelae and those of higher mental functions in PD (Cooper et al., 1991). The effect of this disparity is even more evident when the overall perception is broken into constituent components, static and dynamic, neither of which reached significance. Thus, our results on visuoperceptual function in PD are consistent with other studies in which deficits were found (Boller et al., 1984; Ransmayr et al., 1987; Blonder et al., 1989; Bradley et al., 1989; Netherton et al., 1989; Mohr et al., 1990a,b; Raskin et al., 1990; Levin et al., 1991; Testa et al., 1993) but, as there are many varied aspects to visuoperceptual function, they do not necessarily contradict the contention that there is no generalised visuoperceptual deficit in PD (Brown and Marsden, 1986). After taking the differential in acuity between the PD and control groups into account, the constituent perceptual deficits were relatively subtle. The deficit in static perception (54%) did, however, appear to be the much greater than the probable deficit in dynamic perception (19%) – the latter not having been previously measured in PD. Nevertheless, after removing

the effect of the differential in visual acuity between the two groups, the most striking difference between our approach to measurement of visuoperceptual function and that of all previous studies was the dynamic nature of dynamic perception test, without which no significant deficit would have been found.

Although we have been able to discount motor and visual acuity confounding factors in our demonstration of impaired visuoperceptual function in PD, it is important to ask whether this finding could be explained by some other deficit of higher mental function, in particular general cognition (dementia), sustained visual attention, set-shifting, and central executive function. Dementia could affect performance on a visuoperceptual test which did not necessarily reflect a visuoperceptual deficit. This possibility can be discounted, however, as the experimental subjects had only relatively mild PD and were screened by full neurological examination including measures of orientation and memory. Impairment of sustained visual attention, even if present, should not have affected performance as the maximum sustained attention span required was only 10 s (i.e., dynamic perception test, see Table 2). There is clear evidence that set-shifting is impaired in PD (Robertson and Flowers, 1990; Raskin et al., 1992). However, this should not be a factor within any of the tests as none involves a change of mental set. Similarly, impairment of central executive function in PD (Brown and Marsden, 1991; Dalrymple-Alford et al., 1994) should not affect performance on any of the tests as none involve sharing of resources as is required in carrying out two or more tasks simultaneously.

It is interesting to note that the withdrawal of medication did not affect visuoperceptual performance, especially as there is considerable evidence supporting a role for dopamine in the visual pathways (for review see Jones et al., 1992). Thus, if diminished visual acuity and perception are due to reduced dopamine, reserves of this neurotransmitter may not have been depleted at important visuosensory and perceptual sites 24 h after L-dopa withdrawal or the replacement therapy was ineffective. Alternatively, the visual deficits seen may be due to non-dopaminergic mechanisms.

Although there are a number of areas of study of brain function/dysfunction which could benefit from application of the fractionation technique described, it is important that its limitations be kept in perspective. Firstly, the accuracies of the perceptual resolutions will be limited by the finite quantitization levels of the spacings and maximum spacings in the static and dynamic perception tests respectively (see Tables 1 and 2). Secondly, it would be a gross oversimplification to suggest that visuoperception can be fully quantified by measures such as perceptual resolutions. Other factors are clearly involved in the static and dynamic perception tests, such as arrow shape, whether arrow overlaps the target signal, and, in the dynamic case, the duration for which the maximum spacing is presented. We recognize that what we are calling visuoperception in this paper is somewhat different from what is often meant by interpretation of more complex visual images. Hence, it might be argued that the increased "perceptual" difficulties encountered on the dynamic perception task merely reflect a reduced sensory ability to discriminate a target when it is moving. It appears, however, that this could, at most, be only part of the explanation as no reduction in visual discrimination has been seen when a target is moving over the visual field at 4 deg/s (Westheimer and McKee, 1977), which is of the same order as the speed of target in the dynamic perception task in this study (1.1 deg/s in vertical plane and a maximum 4.4 deg/s in the horizontal plane). In addition, the ability to discriminate was reduced with more complex targets even when they were static (i.e., static perception task versus the visual resolution task).

In summary, despite some limitations, the sensitivity and utility of the fractionation technique presented in this paper has been more than adequately demonstrated. Clearly this technique has considerable scope and potential for application in further studies of PD as well as a variety of other studies of brain disorders in which there are complex visuoperceptual deficits such as stroke, head injury, Huntington's disease, and dementias. The technique could also be applied to study of the normal ageing process in which interpretation of reduced performance on visuospatial/perceptual tests (Cristarella, 1977; Botwinick, 1981; Farver and Farver, 1982; Jones et al., 1986) is complicated by reduced visual acuity (Weymouth, 1960; Cristarella, 1977).

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