Cognitive Impairment in Parkinson's Disease: Is It a Unified Phenomenon?

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Parkinson's disease (PD) has long been associated with dementia. This has been found to correlate with participant age, age at onset of PD and severity of PD. In addition, a large corpus of research points to the fact that participants with, as well as without, dementia can be impaired in a variety of cognitive tasks. Among these, set-shifting and dual-tasking skills have received particular focus. Most studies report that a reduction in attentional resources can lead to problems with these tasks. However, none have been able to determine exactly which systems are involved in these skills and which neurological impairments underlie the observed cognitive deficits. The current study set out to investigate how performance on tasks requiring set-shifting and dual tasking related to each other, as well as overall measures of cognition gained across a variety of tasks. Fifteen participants with PD and 12 control participants underwent screening tests for dementia, as well as specific tests to assess attention, set-shifting and dual tasking. The results indicate that set-shifting ability correlated well with other measures of cognitive performance, whereas dual-tasking skills did not. This could suggest that set-shifting and dual tasking are not necessarily controlled by the same process, or that a particular process is involved to different degrees. In addition, many participants showed individual performance variations and dissociations between tasks that were not necessarily evident from the statistical analysis. This indicates that it can be difficult to make assumptions on overall cognitive performance from specific tasks and vice versa. This observation has implications for clinical practice as well as research methodology.

Parkinson's Disease (PD) is one of the most common neurodegenerative disorders and is particularly prevalent in the aged population. Although the diagnosis of PD is largely based on motor symptoms, a number of concomitant problems are frequently found in this population, such as depression, and more importantly, cognitive dysfunction and dementia. Reports on the prevalence of dementia in PD vary widely. Emre (2003) refers to studies in which results range from 2% (Hietanen & Teravainen, 1988) to 81% (Martin et al., 1973). Emre (2003) suggests that these differences in results are likely to be due to variations in methodology concerning the type of cognitive assessment; the participant groups included — Hietanen and Teravainen's (1988) research, for example, only included early-onset cases; and the age of the patients studied. Age appears to have a particularly strong association with the presence of dementia in PD, both in terms of age at testing (Mayeux et al., 1992), as well as age of onset of PD (Reid et al., 1996). The

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severity of Parkinsonian symptoms has also been linked to the presence of dementia. A variety of motor and cognitive tasks have been compared. Levy et al. (2000), for example, reported significant correlations between dementia and severity of bradykinesia and speech symptoms, Gurd et al. (2001) identified a similar relationship between arm movements and verbal fluency, and Lichter et al. (1988) reported associations between motor scores and visuospatial discrimination as well as perceptual-motor function. A study by Viitanen et al. (1994) investigated these aspects in more detail and found that the likelihood, and type, of cognitive impairment was to some degree dependent on the type, location and laterality of the motor impairment. However, there are also studies that have identified no significant correlations between cognition and motor impairment. Cooper et al. (1991), for example, found strong associations between motor ability and the presence of depression, but only a weak correlation with cognitive impairment. The authors concluded that cognitive and motor control were dissociated early on in the disease process. Such differences in results might be explained by the fact that different motor and cognitive tasks were employed across studies.

Besides focus on factors that correlate with cognitive impairment in PD, a lot of attention has been directed to investigating the nature of these impairments. The correlation between the presence of dementia and the participant's age might not appear surprising, given that dementia can commonly be found in the aged population irrespective of concomitant PD. It is therefore important to establish whether the observed cognitive problems are specific to PD, follow the patterns of normal ageing, or are another form of dementia associated with ageing, such as Alzheimer's disease (AD). Knopman (1998) reviewed the features of different types of dementia that can be encountered in the elderly population, such as AD, dementia associated with PD (also called dementia with Lewy Bodies and classified as a subcortical dementia), dementia associated with stroke, frontotemporal dementia, and rapidly progressing dementia. He indicated that these different types can be distinguished both by their history, as well as presenting cognitive deficits. The distinguishing features between PD and AD have been a focus of many research projects. Aarsland et al. (2001) have identified neuropsychiatric differences in that patients with PD tended to have more severe hallucinations whereas those with AD were more affected by agitation, disinhibition, or euphoria, among others. Cummings (1988) also noted that depression tended to be found in PD rather than AD patients. Specific cognitive functions are more commonly tested to distinguish between the two types of dementia, and deficits in verbal fluency and visuospatial tasks are most frequently reported to show differences (Cummings, 1988; Huber et al., 1989; Stern et al., 1993). In these studies the patients with PD were more impaired in the above functions than those with AD. However, more recent research has indicated that some caution needs to be applied when using verbal fluency as a distinguishing criterion. Gurd (2000) noted that despite the high number of reports of verbal fluency deficits in PD (e.g., Bayles et al., 1993; Flowers et al., 1997; Gurd & Ward, 1989; Stern et al., 1993) these deficits might be specific to individuals rather than applying across the population. This notion was partly supported by Suhr and Jones' (1998) research who found that there were no unique patterns of semantic and letter fluency impairments associated with AD, PD and Huntington's disease (HD). They referred to the contradictory results on the difference between semantic, and letter, fluency in the various patient groups, which might again point to the fact that participants showed individual patterns of impairment.

One important aspect to consider when evaluating research into the cognitive deficits in PD is that some studies used patients with, and others those without, dementia. Gurd's (2000) report on the specificity of verbal fluency deficits, for example, was based on a nonaffected group whereas many other studies used clients diagnosed with dementia. Heterogeneity of participant groups can thus go some way to explaining contradictory results. On the other hand, Suhr and Jones's (1998) research, which also identified individual differences in verbal fluency behaviour, was based only on participants with dementia. Not all differences in results can thus be attributed to whether participants showed signs of dementia or not. Further differences can arise from the fact that the severity of dementia can vary between participants. Girotti et al. (1988), for example, have stated that PD patients with and without dementia essentially show similar deficits but to different degrees. Thus, the severity of dementia also has to be taken into account in the evaluation of results. These studies highlight the importance of obtaining detailed information about general cognitive state when embarking on an investigation of a specific ability such as, for example, verbal fluency.

Besides research on verbal fluency, two areas of cognitive performance have received considerable attention in PD: the ability to shift mental

set (set-shifting), and to carry out concurrent tasks (dual tasking). As discussed by Brown and Marsden (1988), mental sets are established when an action is performed repeatedly. Processing demands decrease due to this repetition. The fact that a set has been formed is evident from faster processing, a reduction in errors, or the ability to free sufficient attentional resources to perform a concurrent task. The downside of establishing sets is that increased resources are needed to change to another type of behaviour; that is, to shift sets. It is this ability to switch between different motor behaviours or cognitive operations that has been found to be impaired in speakers with PD.

While there is agreement about the fact that set-shifting ability is impaired in PD and that this deficit can occur relatively early on in the disease (e.g., Brown & Marsden, 1990; Cools et al., 2001; Gauntlett-Gilbert et al., 1999; Hsieh et al., 1995; Ravizza et al., 2002, 2001; Stout et al., 2001; Tamura et al., 2003; Woodward et al., 2002), there is still some disagreement as to the underlying causes. One of the early conclusions about set-shifting ability in PD was that these participants had a generalised deficit which affected all cognitive and motor operations (Cools et al., 1984, reviewed in Brown & Marsden 1988). Other researchers who found performance dissociations across tasks took the view that the effort required for a task, or the amount of self-directed planning necessary for the task, could determine the presence or degree of set-shifting deficits (e.g., Taylor et al., 1986, reviewed in Brown & Marsden, 1988; Weingartner et al., 1984). Brown and Marsden (1988) claimed that none of these theories could explain the patterns of behaviour observed in patients with PD satisfactorily and instead suggested that the decisive factor was the type of cue available to the participant during the task. More specifically, they found that patients with PD performed better under conditions where they were provided with a cue by the experimenter (external cue) than when they had to cue themselves into the task (internal cue). In addition, Brown and Marsden (1988, 1991) proposed that the problems with internal cueing were not due to an actual problem with internal control, but with limited attentional resources that could be assigned to this process. They concluded that patients with PD have a reduction of resources in the supervisory attentional system (as defined by Norman & Shallice, 1980) and that tasks which require internal control exceed the available resources, thus leading to deficits in performance. This hypothesis has been tested again recently and confirmed by Woodward et al. (2002). In addition, Robertson et al. (1996) also noted disruptions to the supervisory attentional system and thus lent support to Brown and Marsden's (1988) theory.

Similarly, studies have concentrated on the role of the central executive (based on Baddeley's (1986) working memory model). Fournet et al. (1996), for example, investigated whether the observed reduction in central processing resources reflected problems in the central executive system. They found no evidence for an impairment of the central executive in their PD group and concluded that either the system is not affected in all participants, is dependent on the nature of the task, or is influenced by medication. Tamura et al. (2003) also looked into how the working memory system is affected in PD. In contrast to Fournet et al. (1996), they observed deficits in the central executive function in their participant group and concluded that this was due to a depletion of attentional set-shifting resources, rather than a reduction of attentional resources per se.

Although Brown and Marsden's (1988, 1991) theory is widely accepted, there are studies that report contradictory results. Downes et al. (1993), for example, used a set-shifting task based on letter and category fluency and observed both a higher percentage of errors as well as a smaller amount of overall output in the PD group than would be expected. However, although the error percentage was reduced upon the introduction of external cues, the number of retrieved items did not increase as much as anticipated in this condition. Downes et al. (1993) took this as evidence for an impairment of the inhibitory attentional processes; that is, a decision on which dimension attention should be focused on, and which one needs to be ignored. A related theory had been proposed by Taylor and St. Cyr (1992) who concluded that the basal ganglia are involved in reducing irrelevant information during processing. An impairment of the basal ganglia would result in the overloading of the system with unnecessary information and thus a reduction of available resources. However, Stout et al. (2001) tested this hypothesis on participants with HD and PD and only found impairments in the former group. They therefore concluded that although the basal ganglia seem to be involved in the suppression of irrelevant information, not all disorders with basal ganglia involvement show this impairment.

Findings on set-shifting deficits in PD and their exact cause are thus not entirely clear; however, a common strand can be identified in most hypotheses. That is, they propose that somehow participants with PD have to operate on the basis

of reduced attentional resources, irrespective of whether this reduction is based on changes to the attentional system or an overloading of the system due to problems with inhibitory processes. This idea of reduced availability of processing resources links set-shifting ability strongly to dual-task performance, which is another area commonly identified as impaired in PD.

Some of the dual task deficits in PD are reported in relation to carrying out other tasks while walking. In all cases, results indicate that the amount of attention allocated to walking influences gait stability and that impairments can be detected if participants are asked to carry out other tasks such as verbal fluency simultaneously (e.g., Camicioli, 1997, 1998; Darmon et al., 1999; Hausdorff et al., 2003; Woollacott et al., 2002). Similar results have been observed in other motor tasks (Brown & Marsden 1991; Caligiuri et al., 1992; Ho et al., 2002; Jones et al., 1994; Konczak et al., 1997) as well as cognitive tasks such as random letter and digit generation (Robertson et al. 1996). Assumptions about the causes for the deficits are again based on ideas of reduced availability of attentional resources or problems with the appropriate allocation of resources.

The research literature thus generally suggests that similar processing problems underlie the deficits observed in set-shifting as well as dual-task performance of participants with PD. However, despite the sizeable amount of research that has been carried out into specific areas of cognitive deficit in PD no studies have focused on the relationship between these prominent areas of cognitive deficit with each other or with other variables such as severity of PD to our knowledge. Such information could indicate whether they are governed by the same or different processes. This would be clinically relevant as it could inform professionals about the likelihood of deficits in one area being associated with those in other areas. The current study therefore set out to compare the performance of participants with PD and no neurological impairment on general assessments for dementia as well as set-shifting and dual tasking.

Methodology

Participants

Sixteen participants with PD and 12 age-matched nonneurologically impaired controls were analysed in this study. Ages ranged from 59 to 75 years in the Parkinsonian group, with a mean of 66.6 years and a standard deviation of 5.25 years (Table 1). The data reported here form part of a larger study addressing different questions, and as data collection is incomplete, it was not possible to match the two participant groups exactly. However, the fact that all tests applied in this project have themselves been standardised on large populations of unimpaired speakers means that reliable statements could be made about normality of performance despite the slight mismatch in groups.

The severity of PD ranged from 1 to 4 on the Hoehn and Yahr (1969) scale (Table 1). The severity of PD has been linked to cognitive state and is thus an important parameter to consider. As one of the aims of the current study was to investigate the relationship between PD severity and cognitive state, a range of severities were included.

Inclusion and exclusion criteria for this group consisted of a diagnosis of idiopathic PD, an absence of any other neurological problems, absence of depression and sufficient visual acuity and hearing ability to carry out the tests. The same criteria applied to the control group, with the additional requirement of absence of Parkinsonian symptoms.

Information regarding inclusion and exclusion criteria was gathered from medical notes, observation and informal conversation with the participants. In addition, participants were asked to complete a questionnaire (Wakefield Questionnaire for Depression, Snaith et al., 1971) to screen for any signs of depression that had not been identified in the medical notes. Only one participant (PD8) had to be excluded from the analysis as she was being treated for depression.

Test Conditions

Testing of the PD group was carried out in a medicated state. Participants were tested at times when medication had reached maximum effect according to self-reports. Testing would have been stopped had there been signs of drugs wearing off; however, this did not occur.

Testing took place at the participants' homes or at the university. Although participants had the choice to have the assessments spread over two sessions, all elected to go through them within one session. Besides the cognitive tests, participants also underwent a number of speech assessments. These were all carried out after the cognitive tests and were thus unlikely to have affected their results. The results of the speech assessments are not reported in this paper.

Tasks

Sagar (1991) pointed out the importance of comparing performance on specific cognitive tasks, such as set-shifting, with more global cognitive performance. For this reason, two

TABLE 1
Subject Information

Subject	Gender	Age	PD Severity	Medication
PD1	m	66	1	Sinemet, Entacapone
PD2	m	71	2	Madopar
PD3	m	75	1.5	Madopar
PD4	m	63	3.5	Sinemet, Madopar, Entacapone
PD5	f	63	2.5	Madopar, Ropinirole, Amantidine, Zispin Domperidone, Amlodipine, Co-amilofruse, Mirtazapine
PD6	m	62	2.5	Benzhexol, Co-codamol, Amlodipine, Bendrofluazide, Aspirin, Sinemet Plus, Ropinirole
PD7	m	73	4	Nil
PD9	m	67	3	Sinemet, Entacapone, Selegiline, Pergolide
PD10	m	62	3	Amantadine, Sinemet, Ropinirole
PD11	m	71	3	Sinemet, Domperidone
PD12	m	62	2.5	Ropinirole, Domperidone
PD13	m	71	1	Sinemet
PD14	f	59	3	Madopar, Benzhexol, Quinine sulphate, Amitriptyline
PD15	m	60	2	Pramipexole, Finasteride, Quinine bisulphate, Co-Codamol
PD16	m	71	2	Nil
CON1	f	64		
CON2	m	64		
CON3	m	64		
CON4	m	70		
CON5	m	74		
CON6	f	62		
CON7	f	77		
CON8	f	61		
CON9	m	62		
CON10	m	71		
CON11	m	66		
CON12	m	77		

types of cognitive tests were carried out in this study. As an indicator of general cognitive state, the Addenbrook's Cognitive Examination (ACE, Mathuranath et al., 2000) was carried out. In addition, four sections of the Test of Everyday Attention (TEA, Robertson et al., 1994) were presented to the participants to investigate performance on specific cognitive tasks.

The ACE is an extended version of the Mini-Mental-State-Examination (MMSE, Folstein et al., 1975) and returns scores for the MMSE as well as its own subsections. The ACE is designed to be more sensitive than the MMSE to different types of dementia, as well as early signs of AD and symptoms of fronto-temporal problems. It includes all sections of the MMSE, as well as additional tests on memory (episodic memory and learning/recall of information), language (naming, comprehension, repeating words and sentences, regular and irregular word reading, and writing), letter and category verbal fluency, and an expanded version of MMSE's visuospatial tests. The total score for the ACE is 100, with a score of 83 or less (or 88 for greater sensitivity) indicating abnormal performance. Both the ACE and MMSE scores were taken as indicators of the participants' global cognitive performance.

The chosen sections of the TEA related to selective attention, shifting attention, and dual-task performance. Particularly, the latter two areas have been implicated by previous research as impaired in participants with PD. Selective attention was measured predominantly as a control task for the dual-task section. In order to ensure that the single-task performance of the participants was typical, a further selective attention task was presented. The individual tasks were as follows:

Map search. Participants have to look for specified symbols on a map and are assessed after one and two minutes. Test scores relate to the number of correctly identified symbols during each time interval. The authors indicate that this test loads on the same factors as the Stroop Test (Trenerry et al., 1989) and the d2 Cancellation Test (Brickenkamp, 1962).

Visual elevator. Participants have to follow the direction of an imaginary elevator by being visually presented with the 'floors' it passes. The elevator frequently switches direction and participants thus have to count either forwards or backwards. The authors indicate that this test loads on the same factors as the Wisconsin Card Sorting Test. The subtest provides two scores. One indicates how many floors out of 10 the participant counted correctly (accuracy score). As the task is self-paced this score is not influenced by motor impairment. Second, a timing score provides information on how long the individual took per switch (expressed in seconds per switch). This score is calculated on the basis of the correct answers and the total time taken for the correct switches. It is thus susceptible to motor impairments such as problems with initiating speech. If participants provided no correct answers a timing score could not be calculated. In these cases, the score was treated as a missing value (Robertson 2003, personal communication).

Telephone search. Similar to the map search, participants are asked to scan a telephone directory for specific symbols. This test is again concerned with selective attention, and in addition, serves as the control task for the dual tasking subtest.

Telephone search while counting. In this task participants are asked to count strings of tones while carrying out a search for symbols through another telephone directory. Besides providing an indication of the individual's dual task performance, this test also loads on the sustained attention factor. The score is based on the number of correctly identified strings, the number of correctly identified targets in the directory, and the time taken to identify these. The task makes the same demands on the motor system as the single-task version. By adding the scores for the telephone search task into the equation a dual task decrement is calculated that is not affected by slowness of movement due to PD. Raw scores of the test are scaled against normative data for different age groups. These are 50 to 64 years, and 65 to 80 years at the upper range. As the current participants fell into both these categories their scores are controlled for influences of age by using the scaled rather than raw scores. The maximum score for each of the subtests is 19. The normative data provided for the test indicate that a score of 10 (percentile range of 43.4–56.6) is typical for unimpaired adults, whereas a score of 5 (percentile range of 3.3–6.7) or below indicates performance below the normal range. In addition to analysing the scores for the individual subtests, the total of all scores was calculated for each participant (total TEA score) as another indicator of overall cognitive performance for comparison with the ACE and MMSE. No normative values are available for such a score, and comparisons could only be drawn with the current control group in this case.

Statistical Analysis

Statistical tests applied in this study consisted of ANOVAs with post-hoc *t* tests to investigate group differences, as well as calculations of the Pearson's product–moment correlation coefficient to detect relationships between difference tasks. There was the question of whether to apply the Bonferroni correction to the results, and it was decided against this. This decision was based on the fact that the planned comparisons that were made across the conditions represented the primary purpose of this study. As the number of comparisons was reasonably small the null hypothesis could be rejected at the usual per comparison probability level (Keppel et al., 1992). In addition, the significance levels reported in the result section are 2-tailed. As the direction of the difference between the groups was predictable these levels could be halved, in which case they were generally significant even when the Bonferroni correction was applied.

Results

Analysis of the results focused on three different areas. First, we wanted to establish whether the participants' cognitive performance was dependent on their age or the severity of PD. Second, comparisons were drawn between the two groups to determine whether PD participants performed poorer on cognitive tests than neurologically unimpaired participants. Finally, the relationship between different cognitive tasks was investigated for the two groups.

Possible Factors Relating to Cognitive Performance

The data for severity of PD, age and results for the cognitive tests are summarised in Table 2.

TABLE 2
Information on Age and PD Severity and Summary of ACE, MMSE and the Total TEA Scores[1]

Subject	Age	Severity	ACE	MMSE	TEA
PD1	66	1	88	30	34
PD2	71	2	96	29	59
PD3	75	1.5	91	28	45
PD4	63	3.5	70	26	16
PD5	63	2.5	89	29	66
PD6	62	2.5	89	28	46
PD7	73	4	90	29	66
PD9	67	3	77	24	39
PD10	62	3	83	28	35
PD11	71	3	74	28	40
PD12	62	2.5	95	29	63
PD13	71	1	98	29	68
PD14	59	3	68	25	23
PD15	60	2	99	29	59
PD16	71	2	90	28	52
C1	64	0	94	28	63
C2	64	0	97	30	55
C3	64	0	93	28	64
C4	70	0	93	29	74
C5	74	0	80	28	55
C6	62	0	96	29	50
C7	77	0	99	30	84
C8	61	0	91	29	61
C9	62	0	89	29	69
C10	71	0	89	29	66
C11	66	0	97	29	86
C12	77	0	99	29	66

Note. Maximum scores are ACE: 100 (cut-off point 89 [83]); MMSE: 30 (cut-off point 24); and TEA: 114 (0–30: below 6.7th percentile; 31–59: up to 56.6th percentile [typical performance]; 60–114: above 56.7th percentile).

Results suggest that no significant correlation existed between age and severity of PD ($r = -.171$, $p = .393$), nor between age and cognition (Table 3). However, significant relationships could be identified for severity of PD and cognitive performance for the three overall measures (MMSE, ACE and total TEA score), as well as the TEA subtests (Table 3). All results suggest that participants with less severe PD performed better cognitively. In order to control for the effects of severity on the results in subsequent analyses the PD group was split in two at the median, which resulted in a low severity group (PD1) with 6 participants, and a high severity group (PD2) with 9 participants.

TABLE 3
Results of Correlation Analyses for Severity, Age and Cognitive Data

		MMSE	ACE	TEA t	TEA1	TEA2	TEA3	TEA4	TEA5
Severity	*r*	−.509	−.564	−.585	−.481	−.449	−.477	−.568	−.393
	p	.007	.002	.001	.011	.019	.012	.002	.042
Age	*r*	.215	.202	.298					
	p	.282	.311	.131					

Note. Abbreviations: TEA t: total TEA score; TEA 1: map search 1 min.; TEA2: map search 2 min.; TEA3: visual elevator accuracy score; TEA4: telephone search; TEA5: telephone search and counting.

TABLE 4
Scores for Individual Subtests of the TEA

Subject	Map search 1	Map search 2	Elevator accuracy	Elevator timing	Telephone single	Telephone dual
PD1	8	8	4	—	8	6
PD2	8	8	9	12	10	12
PD3	4	7	9	8	8	9
PD4	6	5	2	—	3	3
PD5	12	14	13	8	11	8
PD6	7	7	6	10	7	9
PD7	11	10	12	10	8	15
PD9	8	9	4	—	7	11
PD10	3	5	4	6	3	14
PD11	2	6	9	10	7	6
PD12	12	13	6	14	9	9
PD13	7	8	15	15	11	12
PD14	3	5	2	—	3	10
PD15	8	8	10	12	11	10
PD16	7	9	5	13	11	7
C1	11	10	7	7	9	19
C2	10	10	7	9	9	10
C3	10	10	13	9	10	12
C4	11	13	15	13	11	11
C5	9	9	9	10	8	10
C6	5	6	10	12	5	12
C7	14	12	15	14	14	15
C8	10	10	7	10	10	14
C9	11	13	10	11	12	12
C10	11	11	12	12	11	9
C11	15	16	11	15	14	15
C12	10	10	12	12	11	11

Note. The maximum score for each subtest is 19. Scores of 5 and below are regarded as abnormal (below the 6.7th percentile), scores of 10 indicate the typical performance 45.7th to 56.6th percentile). Missing values indicate cases where no timing score could be calculated due to poor accuracy on the same task.

Comparison Between PD and Control Participants

First, an ANOVA was carried out to test for differences between PD and control participants in relation to the TEA. Individual results for the subtests of the TEA are presented in Table 4. As can be seen, some participants had missing values for the visual elevator task due to poor performance on the accuracy score and the ANOVA was therefore calculated without the timing scores.

The ANOVA comparing PD and control participants indicated a significant main effect of both experimental group $F(2,24) = 6.79$, $p = .005$ and condition $F(4,96) = 3.02$, $p = .022$.

Post hoc t tests showed significant differences between groups for the overall score of the TEA (Table 5). In addition, a number of other subsections showed significant differences between the groups (Table 5). When the same analysis was carried out with the split PD group, results remained similar. There was again a significant main effect of both experimental group $F(1,25) = 12.77$, $p = .001$ and condition $F(4,100) = 3.37$, $p = .012$. In addition, significant differences could be identified between PD1 and control participants for the map search scores and the dual telephone search task (Table 5). The comparison between PD2 and the control group indicated differences for all but the map search task (Table 5). The comparison between the two PD groups only showed differences in the simple telephone search task (Table 5). Significant differences could thus be identified for all subtests of the TEA between the control and at least one subgroup of the PD participants although not many tasks differentiated between the PD participants themselves. It should be noted

TABLE 5
Post-hoc Independent Samples *t* test for Equality of Means ($p < .05$)

Control vs. all PD subjects	*t* — equal variances assumed	*df*	Sig. (2-tailed)
TEA total score (based on 11 subjects only)	3.790	26	.001
Map search 1 min.	–3.338	26	.003
Map search 2 min.	–2.887	26	.008
Visual elevator accuracy	–2.511	26	.019
Telephone search single	–2.518	26	.018
Telephone search dual	–2.709	26	.012
Control vs. PD1			
Map search 1 min.	–3.227	16	.005
Map search 2 min.	–2.716	16	.005
Visual elevator accuracy	–1.234	16	.235
Telephone search single	–0.449	16	.660
Telephone search dual	–2.329	16	.033
Control vs. PD2			
Map search 1 min.	–2.478	19	.023
Map search 2 min.	–2.008	19	.059
Visual elevator accuracy	–2.796	19	.012
Telephone search single	–3.310	19	.004
Telephone search dual	–2.145	19	.045

that the map search and telephone search tasks required fast motor responses and significant differences are not solely reflective of poorer cognitive performance of the PD participants. The results of the visual elevator accuracy as well as the telephone search with counting scores are thus more indicative of differences between groups in relation to cognitive performance.

A further qualitative analysis was carried out for the subtests on set-shifting and dual-task performance, as these were of particular focus in this study. The statistical data indicate that for both of these subtests significant differences existed between the PD group and the current control group. The fact that the TEA has been standardised on a larger population allows further comparisons of the PD group in relation to normality. The TEA manual suggests that a scaled score below 5 — that is, within a percentile range of 3.3 to 6.7 — represents abnormal performance. In addition, a scaled score of 10 represents a more typical performance (percentile range of 43.4 to 56.6). If the current PD data are evaluated against these norms, it can be seen that for the accuracy score of the set-shifting task, 6 participants performed in the abnormal range. On the other hand, 4 of the remaining participants had scores at or above 10 and thus performed relatively well compared to a larger population of unimpaired adults. For the timing score of the same task even more PD participants performed in the upper end of the normal range, as 8 of the participants had scores at or above 10. If one ignores the 4 participants whose timing score could not be calculated due to poor accuracy, none of the PD participants fell outside the normal range. For the dual task test, a similar pattern emerges, as only one had a score below 5 and 7 had scores at or above 10.

Although it was thus true that the PD participants performed significantly worse than the current control group, the majority of the group still fell within the normal range when compared to a larger population of unimpaired adults. In addition, the individual data suggest that the set-shifting task was more problematic for PD participants than the dual-task test.

Further comparisons between PD and control participants were drawn for the MMSE and ACE. The individual data (Table 6) show that for the MMSE, only 3 PD participants (PD 4, 9 and 13) performed below the current normal range and, of those, only 1 (PD 9) was identified as showing signs of dementia according to the test criteria. Similarly, 3 PD participants performed below the current normal range for the ACE; however, a further 4 participants performed near the lower range of the control group, thus indicating a generally poorer performance of the PD participants in this test. According to the ACE criteria, 6 PD participants and 1 control participant showed signs of dementia,

TABLE 6
Summary of Total Scores for the ACE and MMSE, as Well as the ACE Subsections

Subject	MMSE	ACE	Orientation	Attention	Memory	Verbal fluency	Language	Visuo-spatial
PD1	30	88	10	8	29	10	28	3
PD2	29	96	10	8	34	13	27	4
PD3	28	91	10	8	30	13	27	3
PD4	26	70	10	7	24	2	24	3
PD5	29	89	10	8	27	12	27	5
PD6	28	89	10	8	29	13	24	5
PD7	29	90	10	8	29	11	27	5
PD9	24	77	10	5	26	7	25	4
PD10	28	83	10	8	23	10	27	5
PD11	28	74	10	8	13	11	28	4
PD12	29	95	10	8	33	12	27	5
PD13	29	98	10	8	34	13	28	5
PD14	25	68	10	7	18	5	27	1
PD15	29	99	9	8	35	14	28	5
PD16	28	90	10	8	27	13	27	5
C1	28	94	10	8	31	13	28	4
C2	30	97	10	8	34	13	28	4
C3	28	93	10	8	30	12	28	5
C4	29	93	10	8	33	13	24	5
C5	28	80	10	8	23	7	28	4
C6	29	96	10	8	32	13	28	5
C7	30	99	10	8	34	14	28	5
C8	29	91	10	8	30	11	28	4
C9	29	89	10	8	26	12	28	5
C10	29	89	10	8	30	8	28	5
C11	29	97	10	8	33	13	28	5
C12	29	99	10	8	35	14	28	4

Note. Maximum scores are ACE: 100 (cut-off point 88 [83]); and MMSE: 30 (cut-off point 24). There are no cut-off points for any of the subtests of the ACE.

narrowing down to 4 PD and 1 control participant when the stricter cut-off point was applied.

The individual data are confirmed by the statistical analysis. Results for the *t* test indicate no significant group differences for the MMSE ($p = .067$). A univariate ANOVA examining MMSE scores with three groups (PD1, PD2 and controls) indicated a significant main effect of experimental group $F(2,24) = 7.27$, $p = .017$. Post-hoc *t* tests showed this to be due to a significant difference between the PD2 and control group ($p = .013$).

In contrast to the MMSE scores, the comparison between the PD and control participants was significant for the ACE, albeit just below the 5% level ($p = .049$). A univariate ANOVA examining the ACE scores with three groups (PD1, PD2 and controls) again indicated a significant main effect of experimental group $F(2,24) = 8.18$, $p = .002$. This time the post-hoc *t* tests suggested significant differences between the PD2 and PD1 group ($p = .016$) as well as between the PD2 and control participants ($p = .003$).

Interestingly, none of the subsections of the ACE showed significant differences between the two groups. This could indicate that participants were differentially affected across the various sections of the ACE, a fact which was supported by the analysis of the individual data (Table 6). Performance was generally good for attention, orientation and visuospatial tasks, and participants showed a variety of deficit patterns across the other sections.

Comparison of Different Cognitive Tasks With Each Other

Correlations between the three cognitive test scores were significant, suggesting that they were

all sensitive to the pattern of cognitive impairment (MMSE-ACE: $r = .762$, $p = .001$; MMSE-total TEA: $r = .905$, $p = .000$; ACE-total TEA: $r = .698$, $p = .017$).

Further analyses were carried out to assess how dual task and set-shifting performance related to each other as well as general cognitive performance. Individual scores for these tests can be found in Tables 4 and 6. The PD and control groups were analysed separately to be able to identify any dissociations between patterns of cognitive performance.

The results indicated that there were no significant correlations between the dual-task performance and the MMSE, ACE or any of the other subtests of the TEA in any of the groups. Most important here is the absence of a correlation between the dual task and set-shifting task, as well as the single-task performance (map search and single telephone search).

The analysis for correlations between set-shifting (visual elevator task) and other cognitive tests yielded a higher number of significant results; that is, set-shifting ability correlated positively with the scores for the MMSE ($r = .578$, $p = .024$) and the ACE ($r = .639$, $p = .010$), as well as with the total TEA scores ($r = 818$, $p = .000$) and the telephone search subtest ($r = .707$, $p = .003$) in the PD group.[2] In the control group, only the correlation between the accuracy and timing score of the visual elevator task was significant ($r = .659$, $p = .020$). The lack of significant correlations in the control group could indicate a ceiling effect, as most control participants were in fact not impaired on these tests. Performance across the tasks fell into a relatively narrow range and variations on a small scale were possibly quite arbitrary and certainly not indicative of a deficit. This contrasts with the PD participants who showed greater differences between tasks and whose performance could be labelled as normal or abnormal.

One further calculation was carried out to investigate the relationship between dual tasking and set-shifting. So far the analysis had been based only on the accuracy score of the set-shifting task due to the missing values for the timing score for some participants. As it was possible that the lack of correlation between the tasks was due to the wrong measure of set-shifting being compared, it was considered important to also include these scores in the analysis. The new calculation was based on data excluding the 4 participants with missing values; that is, only 11 PD participants. The statistical analysis showed the timing score only correlated significantly with the single telephone search task ($r = .671$, $p = .024$).

Thus, the results indicate that in the PD group set-shifting performance correlated with overall measures of cognitive performance (MMSE, ACE, total TEA score), as well as with the selective attention measure (single telephone search). However, dual-task performance could not be predicted from any of the other tests of cognitive performance.

Discussion

This study was an exploratory investigation into the cognitive function of participants with PD across a variety of tests, with a particular focus on set-shifting and dual tasking ability.

The results on factors affecting cognitive function were in line with previous research in relation to the significant correlations identified between the severity of PD and cognitive performance (Gurd et al., 2001, Levy et al., 2000, Lichter et al., 1988, Viitanen et al., 1994). The lack of a significant relationship between age and cognitive function could have been due to the fact that the current group included relatively few participants who actually showed signs of dementia. Although previous studies identified a correlation between age and the presence of dementia (e.g., Mayeux et al., 1992), not much information is available about how the range of performance in the nondemented performance band relates to age.

In relation to the tests' sensitivity to cognitive impairment in PD, the current study has shown that the TEA and ACE indicated significant differences between the groups whereas the MMSE did not. These results were expected. The subtests of the TEA included in this study were specifically selected for functions that have been highlighted as problematic in individuals with PD. In addition, the ACE had been chosen instead of the MMSE because it was suggested to be more sensitive to the type of dementia associated with PD (Mathuranath et al., 2000). The current study lends further support to this claim.

Despite the significant differences between the two groups identified in the tests, a more qualitative analysis of the data revealed that these patterns could not be generalised to all participants. Thus, there were PD participants with high severity ratings who performed very well in the cognitive tasks. The participant with the greatest severity (PD7), for example, had considerably better scores for the TEA than one of the participants with the mildest severity rating (PD1).

In addition, the analysis of the subtests and overall scores revealed considerable performance variations. PD7 performed better than most control participants in the dual-task condition, as his

performance in this task was actually better than under the single-task condition. However, his ACE score of 90 is relatively near the cut-off point for dementia of 88. Similarly, PD10 had scores in the abnormal range in the visual elevator and single telephone search tasks of the TEA, but fell above the typical performance for the dual-task condition. These results suggest performance dissociations across different cognitive tasks. The dual-task condition appeared particularly affected by these, and this assumption was supported by the lack of significant correlations between this and any of the other measures of cognitive performance. Our results thus add to previous evidence for performance dissociations between tasks and within PD individuals, such as reported by Gurd (2000) or Suhr and Jones (1998) on verbal-fluency tasks.

One particularly significant aspect of the above finding is the fact that dual-task performance did not correlate with set-shifting ability. Previous research that has looked into these two aspects independently has put forward explanations along the same lines for both tasks; that is, either a depletion of attentional resources (due to pathology or impaired inhibitory processes), or a problem with the appropriate allocation of resources. Given the fact that the current results indicate uneven impairments across the two tasks, it seems unlikely that the same system, process or impairment is responsible for the observed performance. At least, there might be different degrees of involvement; alternatively, completely different areas of attentional control might be implicated in the tasks. The current study was not set up to investigate which processes are responsible for set-shifting and dual-tasking ability and no answers can thus be provided to this question. However, the data do suggest that the set-shifting performance was more related to ability in selective attention tests and the other types of cognitive performance assessed in the ACE, and similar systems seem to be involved in the control of these aspects. However, more research is necessary to be able to make any reliable statements to this regard and future studies need to look more closely at a variety of cognitive tasks to identify how attention is controlled in normal as well as impaired adults.

In conclusion, the current study has demonstrated that participants with PD of all ages and severity can have cognitive problems. These problems were not restricted to particular modalities or cognitive functions. Although the statistical analysis suggested patterns of impairment that confirmed previous research, individual data indicated performance dissociations across tasks in many of the participants. Although this was mainly a feature of the PD group, a number of control participants showed a similar pattern. These results highlight that further research is necessary into the processes that govern performance on a range of cognitive tasks. Most importantly, they show that it would be unwise to make assumptions about the presence or degree of impairment on the basis of a few cognitive assessments. While correlations might be significant on a group basis, individuals do not necessarily follow this pattern. Any clinical evaluation therefore needs to ensure that all relevant areas are assessed in detail. Similarly, research studies need to specifically control for the presence or absence of particular impairments rather than assuming these on the basis of other test results.

Endnotes

1 Due to the fact that four PD subjects had missing values for the visual elevator timing score of the TEA (see Table 3), the TEA total score was only calculated on the basis of the remaining five subtests.

2 The timing score for the visual elevator task was excluded from these calculations.

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