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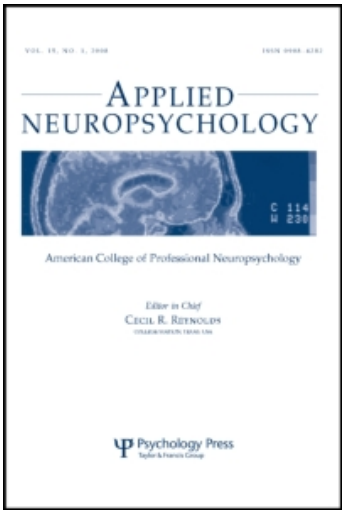

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Assessing Cognitive Impairment in Parkinson's Disease: A Comparison of Two Tower Tasks

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Assessing Cognitive Impairment in Parkinson's Disease: A Comparison of Two Tower Tasks

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This study examined whether two tower tasks—the Cambridge Automated Neuropsychological Test Battery "Stockings of Cambridge" (CANTAB-TOL) and the Delis-Kaplan Executive Function System (D-KEFS-TOH), are interchangeable for detecting cognitive deficits in Parkinson's disease (PD) patients. Forty PD patients who met the criteria for this study were assessed with both tasks. The relative contribution of working memory and inhibition was also examined. Relative to controls, PD patients were impaired on the CANTAB-TOL but not the D-KEFS-TOH. Regression analysis which showed that whereas performance on the CANTAB-TOL task was dependent on inhibition and spatial working memory, performance on the D-KEFS-TOH was dependent on spatial working memory only. Only 7% to 24% of the variance between the two tasks was shared. These findings suggest that these tower tasks from two well-established neuropsychological test batteries are not interchangeable.

Key words: *inhibition, Parkinson's disease, planning, Tower of Hanoi, Tower of London, working memory*

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Variations of the Tower of Hanoi puzzle (TOH) and Tower of London task (TOL) have been employed to assess deficits for patients with a variety of disorders including Parkinson's disease (PD) (Hanes, Andrewes, Smith, & Pantelis, 1996; Owen, Downes, Sahakian, Polkey, & Robbins, 1990; Riccio, Wolfe, Romine,

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Davis, & Sullivan, 2004). As Welsh, Satterlee-Cartmell, and Stein (1999) have pointed out, these two tasks are generally considered to be interchangeable as they purport to measure the same cognitive processes including planning. The ability to plan is an executive function in which the prefrontal cortex has pre-eminence (Cools, Stefanova, Barker, Robbins, & Owen, 2002; Fuster, 2001; Ranganath, Johnson, & D'Esposito, 2003). Because fronto-striatal degeneration is known to occur during PD, planning deficits are a distinct possibility in patients with this disorder.

Multiple variations of tower tasks have been used to assess planning in PD (Culbertson, Moberg, Duda, Stern, & Weintraub, 2004; Leiguarda et al., 1997; Morris et al., 1988; Owen et al., 1992; Saint-Cyr, Taylor, & Lange, 1988). For example, Culbertson et al. reported that a group of 65 PD patients (mean Hoehn & Yahr = 2.27) performed significantly worse, compared to controls, in terms of average total moves and rule and time violations. This study used the TOL-Drexel which is similar in construction to Shallice's TOL task (Shallice, 1982). However, Morris et al. (1988) previously reported no difference in the average number of moves taken by their subjects to complete the tower problems, although the PD patients took longer to think about or plan the solution. The tower task used by Morris et al. was a computer variation of the TOH task, but used colored rectangular blocks instead of balls. The findings by Morris et al. were supported by Saint-Cyr et al. who reported that non-medicated PD patients with mild symptoms showed no impairment in problem solving accuracy using a three-disk version of the Tower of Toronto (a variation of the TOH task). Finally, Owen et al. examined outcomes for three subgroups of PD patients, divided according to disease stage—early non-medicated, mild to moderate stage medicated, and late stage medicated. Owen et al. reported that PD patients spent longer planning solutions compared to controls. Further, increased errors in execution of solutions were evident for patients in the later stages of the disease. Owen et al. used a computerized tower task, "Stockings of Cambridge," from the Cambridge Neuropsychological Test Automated Battery (CANTAB-TOL). The CANTAB-TOL consists of two sets of three colored balls, one in the top half of the screen and the other in the bottom half, which hang in pockets similar to billiard or snooker balls.

Overall, results of studies which have assessed planning deficits in PD patients using the tower task are mixed (McKinlay et al., 2008). Although differences in disease severity and medications may account for some of this variability, the use of different versions of tower tasks may also have contributed to the inconsistent results (Berg & Byrd, 2002; Unterrainer, Rahm, Halsband, & Kaller, 2005). To the extent that different tower tasks vary in terms of the cognitive tasks required for their execution, such tasks might not constitute equivalent measures of planning deficits in PD. Thus the aim of the present study was to compare performance of PD patients with matched controls using tower tasks from two well-established neuropsychological test batteries, the CANTAB—tower task (Stockings of Cambridge), which is based on Shallice's TOL, and the Delis-Kaplan Executive Function System – tower task (D-KEFS-TOH), which is a version of the TOH. If these two tower tasks are functionally equivalent, then a similar pattern of deficits should be revealed for both tasks, and the level of shared variance should be high.

We were also interested in investigating whether any deficits shown by the PD patients on these tower tasks might be linked with specific cognitive processes. If the two tasks are not functionally equivalent then we could expect that different cognitive processes would be recruited in their solutions. Measures of working memory and inhibition were selected to investigate this as these have previously been found to be important for the successful execution of the tower tasks (Welsh et al., 1999). We planned to conduct correlation and regression analyses to determine whether the relationships between task performance and cognitive skills were the same for both tower tasks and whether differences between PD patients and controls might be attributed to deficits in working memory or inhibition.

METHOD

This study received approval from the Canterbury Ethics Committee. All patients with PD were on anti-parkinsonian medication and were tested while medicated.

Participants

PD Group

PD patients in the Canterbury region who could be identified at the time of this study who did not have a diagnosis of dementia were invited by letter to participate. Patients were required to meet the following inclusion criteria: 1) a diagnosis of idiopathic PD confirmed by a neurologist who specialised in motor disorders; 2) assessed as Hoehn and Yahr stage I-IV (stage 1, $n = 8$; stage 1.5, $n = 6$; stage, 2, $n = 7$; stage 2.5, $n = 10$; stage 3, $n = 7$; stage 4, $n = 2$) (Hoehn & Yahr, 1967); 3) aged between 50 and 80 years; 4) adequate or corrected hearing and vision (self-report checked by examiner); 5) stable on PD medication; and 6) English as the primary spoken language.

Patients were excluded for the following reasons: 1) currently involved in a therapeutic trial; 2) suspicion

of dementia symptoms, assessed as a Mini Mental Status Examin (MMSE) (Folstein, Folstein, & McHugh, 1975) score of <25; 3) diagnosis of a learning disability; 4) major depressive episode in the previous six months; 5) premorbid IQ estimated at <85 using the National Adult Reading Test (Nelson & Willison, 1991); 6) currently taking medications known to have a significant effect on the central nervous system (other than medications prescribed for the control of PD symptoms); 7) presence of depression, assessed as Beck Depression Inventory-II (BDI-II) (Beck, Steer, & Brown, 1996) score of >16 or; 8) a history of: a) moderate or severe head injury; b) stroke or other neurological impairment; c) major medical illness; or d) significant psychiatric illness requiring hospitalisation.

Of the 115 letters that were mailed, six of 115 (5.2%) individuals with PD could not participate due to illness, six of 115 (5.2%) were deceased, eight of 115 (6.9%) declined, 34/115 (29.6%) did not respond, and 21/115 (18.3%) did not meet the inclusion/exclusion criteria. After exclusions, 40 participants with PD were avaliable for inclusion in this study.

Controls

Controls were recruited from a number of sources including a previously established database, advertisements at local clubs (bowling, hiking, and table tennis) and businesses. All controls were given a brief outline of the study on first phone contact. If they were still willing to participate, they were then sent an information sheet. In addition to adequate or corrected hearing and vision and being aged between 50 and 80 years, the same exclusion criteria listed above applied.

Procedure

Assessments were carried out over two sessions, scheduled at least one week apart. Tests were presented in a fixed order with breaks taken as required. Tower tasks were presented in counterbalanced order with approximately half of the patients (16/40) and controls (19/40) completing the D-KEFS-TOH first. The experimenter was present during all testing. Written consent was obtained from participants at the start of the first testing session after the study had been explained. Information pertinent to the inclusion/exclusion criteria was elicited from all participants during the first session using a semi-structured interview.

Measures

CANTAB

The CANTAB provides a computerized series of tasks using a touch-sensitive screen. Three tasks from the CANTAB were used and included: 1) Stockings of Cambridge (CANTAB-TOL); 2) Spatial Span; and 3) Spatial Working memory. Further details regarding the different tasks and procedures may be found in Owen et al. (1990).

TOL. The CANTAB-TOL is a computerized version of the TOL (Shallice, 1982). For this task, the participant was shown two displays of three colored balls. The participant was required to rearrange the balls in the bottom half of the screen to match the arrangement in the top half of the screen. A total of 12 test problems were administered. The minimum number of moves required to solve each problem varied from two to five moves (2×2 move, 2×3 move, 4×4 move and 4×5 move). If a participant was unable to solve three consecutive problems in the maximum allowable number of moves, the task was discontinued. Three outcome measures were generated from this task: Number of successfully completed problems, number of problems completed in the minimum number of moves, and total score. This last score was generated by adding the average number of moves for the two, three, four, and five move problems. The maximum possible number of moves (two times the minimum number of moves plus one) was allocated to participants who were unable to complete a given trial. Total possible scores ranged from a minimum of 14 to a maximum of 31 moves.

Spatial span. The CANTAB spatial span task, a computerized version of the Corsi Block tapping task (Milner, 1971), was used to assess spatial working memory. In this task, a random pattern of nine white boxes appeared on the screen. Some of the boxes changed color for a brief period to indicate a sequence. After a brief delay, the participant was required to touch the boxes in the same order that they had changed color. Sequences varied in length from two to nine boxes. If a participant failed to remember the sequence correctly, another trial at that level was given. If the participant failed on the second trial at that level, the task was discontinued. Spatial span was determined by the longest sequence correctly remembered by the participant.

Spatial working memory. For this task, participants were required to find a blue token hidden in a group of randomly arranged boxes without looking in a box more than once. Boxes were opened by touching each one so that it opened to reveal its contents. Once the token was found, the participant placed it in an empty column on the side of the screen. Then a new token was hidden in a different box and the participant searched again. The process was repeated until all the boxes had been used to hide the token and the column at the side of the

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screen was filled. There were four practice trials, each with three boxes, and then there were test trials which included four trials with four, six, and eight. Total number of boxes opened to complete all trials was used as a measure of spatial working memory performance with higher scores being indicative of poorer performance.

Daneman and Carpenter Reading Span Test (Daneman & Carpenter, 1980)

This test was used to assess the participants' verbal working memory (Waters & Caplan, 1996) and involved the presentation of sets of two to six sentences, each consisting of eight to 13 words. Each set of sentences had three trials with 60 sentences in total. Testing began with sequences of two sentences. Participants were asked to read each sentence out loud, judge the veracity of the statement, and remember the last word in each sentence (e.g., the hamburger bit into the juicy man). At the end of each trial, which was signaled by a blank card, the participant was asked to recall as many of the last words as possible. Spans ranged from 1.5 to 6. The test was discontinued if the participant was unable to remember the last word from any of the sentences in a trial set. The reading span was determined as the maximum number of sentences remembered with more than 66% accuracy (two out of three trials correctly recalled). A point was given if the participant remembered one of the sequences in a given trial.

D-KEFS (Delis, Kaplan, & Kramer, 2001)

Two of the nine subtests were selected for use from this battery. Subtests were administered according to procedures outlined in the manual. For each subtest, raw scores were converted to age-corrected scaled scores (mean 10 and *SD* 3).

D-KEFS-TOH. This variant of the TOH consisted of five discs, which varied in diameter from large to small, and a board with three vertical pegs of equal size. For each of the nine problems, the participant was presented with a picture of the tower to be built and two to five discs (depending on the level of difficulty of the tower) on the board in a predetermined starting position. Participants were asked to plan their moves prior to starting while observing two rules: Never place a larger disc on top of a smaller disc, and only move one disc at a time. The task was discontinued after failure to complete three consecutive problems in the allotted time. Three scores were generated for this task: an age-adjusted total score, number of problems completed in minimum moves, and total problems completed successfully. Because there is no maximum number of allowable moves, the total number of moves was not used as an outcome measure for this task. For the age-adjusted score, a raw score was first calculated that included bonus points, which were allocated on the basis of the number of moves made and faster completion times.

Color-word interference test. This test measured the participants' ability to inhibit automatic verbal responses. Participants were required to respond to four separate conditions. In the first condition, participants were presented with a page with rows of colored patches that they were required to name, and in the second condition, they were given a page with rows of words that they were required to read. The third condition is the traditional "stroop effect" where the participants were presented with a page of words printed in dissonant ink colors and asked to name the color of the ink that the letters are printed in rather than reading the word. In the fourth and final condition, the inhibition-switching task, participants were presented with a page with rows of words again printed in dissonant ink colors, but in this condition, some of the words were in boxes. The participant was required to name the color of the ink for the words that were not in boxes but to read the word if the word was inside a box. For each condition, participants were required to name the colors or read the words as quickly as possible without skipping any or making any mistakes. Time taken to complete each condition was recorded and then converted to a standardized score according to procedures outlined in the manual. Results from the third and fourth condition were used as measures of inhibition.

RESULTS

Patients were well matched to healthy controls in terms of age and premorbid IQ (Table 1), but differed in terms of symptoms consistent with low mood (as measured by the BDI-II) and current mental status (as measured by the MMSE). However, no patient met the criteria for a depressive episode or dementia (*Diagnostic and Statistical Manual of Mental Disorders* (DSM-IV) criteria). It should be noted that PD patients tend to score more highly on the BDI-II than healthy individuals because of the somatic aspects of this questionnaire, and it is unlikely that this difference represents a difference in mood (Leentjens, Lousberg, & Verhey, 2002). Further, whereas a significant difference was found between the two groups for current mental status using the MMSE, the effect was relatively small ($d = .43$) (Cohen, 1988).

As shown in Table 2, the PD group performed more poorly than controls on the CANTAB-TOL, completing significantly fewer towers in the minimum number of moves and on average requiring more moves to solve the problems. The PD group also solved fewer

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TABLE 1
Clinical and Demographic Characterstics, Parkinson's Disease Group Versus Controls

	Parkinson's Disease (n = 40)		*Control Group (n = 40)*			
	Mean	*SD*	*Mean SD*	*SD*	*t value*	*p value*
NART[1]	109.05	10.13	111.20	10.30	0.94	>0.30
Education (yrs)[2]	13.94	2.56	13.76	2.57	−0.30	>0.75
Age	66.15	6.65	66.58	5.47	0.31	>0.75
MMSE[3]	28.65	1.42	29.58	0.71	3.67	<0.001*
BDI-II[4]	7.59	4.34	4.13	3.39	−3.96	<0.001*
PD onset[5]	6.49	4.35				

[1]National Adult Reading Test used to estimate premorbid IQ.
[2]Total number of years of formal education.
[3]Mini Mental Status Exam
[4]Beck Depression Inventory-II
[5]Number of years since diagnosis of Parkinson's disease.
*Significant group difference.

CANTAB-TOL tower problems, but this difference fell short of significance ($p < .06$). By contrast, there were no differences between the groups on the D-KEFS-TOH (see Table 2). Effect sizes for outcome measures on the CANTAB-TOL ranged from medium to large, whereas those for the D-KEFS-TOH were all small. The PD group also showed deficits for two of the three working memory tasks (spatial span and reading span) and on both measures of inhibition.

Correlations were used to examine whether any planning deficits, as measured by the tower tasks, were linked to cognitive processes. As can be seen in Table 3, only low-to-moderate correlations were found for PD patients on the two tower tasks ($r = .27$ to $r = -.49$), indicating that between 7% to 24% of variance in the tasks was shared. In terms of working memory measures, only spatial span showed a significant positive correlation with all outcome measures on CANTAB–TOL. Spatial working memory was only significantly associated with the number of towers solved in minimum moves, and the verbal working memory task was significantly associated only with the number of towers correctly solved (see Table 3). Both measures of inhibition showed a moderate correlation with the CANTAB-TOL. A stronger pattern was evident between performance on the D-KEFS-TOH and measures of working memory with significant positive correlations evident for both spatial span and spatial working memory. There were

TABLE 2
PD Group Compared to Controls on Two Tower Tasks and Working Memory Tasks

	Controls Mean (SD)	*PD Patients Mean (SD)*	*t value*	*p value*	*Cohen's d*
CANTAB- TOL[1]					
Number solved in minimum moves	8.1 (2.1)	6.6 (2.6)	2.81	<**0.01***	0.60
Number correctly solved	10.3 (1.6)	9.4 (2.8)	1.80	<0.06	0.39
Total number of moves used[2]	18.1 (2.7)	20.1 (4.1)	2.62	<**0.02***	−0.58
D-KEFS TOH[3]					
Number solved in minimum moves	4.2 (1.2)	4.1 (1.1)	0.50	>0.60	0.09
Number correctly solved	7.0 (1.7)	6.8 (1.5)	0.62	>0.50	0.13
Age adjusted scaled score	10.3 (3.1)	9.8 (2.6)	0.80	>0.40	0.17
Working Memory Tasks					
Spatial Span	5.2 (1.1)	4.6 (0.7)	2.78	<**0.01***	0.65
Spatial Working Memory[4]	186.6 (19.9)	195.0 (18.1)	1.97	<0.06	−0.44
Daneman & Carpenter	2.5 (0.7)	1.7 (0.6)	5.73	<**0.001***	1.23
Inhibition Tasks[5]					
Inhibition	11.6 (2.3)	9.1 (3.3)	3.87	<**0.001***	0.88
Inhibition Switching	11.8 (2.3)	9.1 (3.7)	4.0	<**0.001***	0.88

[1]Cambridge Automated Neuropsychological Test Battery-Stockings of Cambridge
[2]Total average number of moves made.
[3]Delis-Kaplan Executive Function System Tower Task
[4]ctal number of moves; Higher scores indicate greater impairment.
[5]Delis-Kaplan Executive Function System Color-Word Interference Test
*Significant group difference.

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TABLE 3
Correlation between Tower of Hanoi, Tower of London, Working Memory, and Inhibition Measures for Parkinson's Disease Patients

	CANTAB-TOL			*D-KEFS-TOH*					
	(N) Solved in Min Moves	*(N) Correctly Solved*	*Total Number of Moves*	*(N) Solved in Min Moves*	*(N) Correctly Solved*	*Age-Adjusted Scaled Score*	*Spatial Span*	*Spatial Working Memory*	*Inhibition*
CANTAB- TOL[1]									
(N) Solved in min moves									
(N) correctly solved	**0.88*****								
Total number of moves[2]	**−0.94*****	**−0.92*****							
D-KEFS-TOH[3]									
(N) solved in min moves	**0.39***	0.27	**−0.41****						
(N) correctly solved	**0.46****	**0.43****	**−0.49****	**0.41***					
Age adjusted scaled score	**0.44****	**0.35***	**−0.47****	**0.80*****	**0.79*****				
Working Memory Tasks									
Spatial Span	**0.37***	**0.47****	**−0.41****	0.26	**0.46****	**0.36***			
Spatial Working Memory[4]	**0.34***	0.15	−0.28	**0.42****	**0.41****	**0.53****	−0.23		
Reading Span[5]	0.30	**0.38***	−0.30	0.09	0.30	0.20	**0.43****	**−0.36***	
D-KEFS Color Word[6]									
Inhibition	**0.49****	**0.48****	**−0.53****	**0.38***	**−0.41****	**0.40***	**0.45****	**−0.34***	
Inhibition Switching	**0.43****	**0.36***	**–0.45****	0.21	0.14	0.25	**0.36***	−0.20	**0.50****

[1]Cambridge Automated Neuropsychological Test Battery-Stockings of Cambridge
[2]Total average number of moves taken.
[3]Delis-Kaplan Executive Function System Tower Task
[4]Scores for this task were inverted so that a higher score indicated good performance.
[5]Daneman and Carpenter Reading Span Task
[6]Delis-Kaplan Executive Function System Color-Word Interference Task
$^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

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no significant correlations between verbal working memory, and only one measure of inhibition was associated with the D-KEFS-TOH (see Table 3).

The level of shared variance between the two tower tasks for healthy controls was similar to that for PD patients ($r = .28$ to $r = -.61$; 7% to 37% shared variance), but the pattern of performance across related tasks differed (see Table 4). Among measures of working memory, only spatial working memory was significantly correlated with tower performance. This finding was consistent across both tasks. By contrast, there were no significant correlations with the spatial span task or verbal working memory for both the CANTAB-TOL and D-KEFS-TOH (see Table 4). Inhibition was related to performance on the CANTAB-TOL but not with performance on any aspect of the D-KEFS-TOH.

We conducted regression analyses to test whether deficits shown by the PD patients on the CANTAB-TOL task were due to deficits in spatial working memory, inhibition, or both. For these analyses, group (PD vs. control) and spatial working memory (or simple inhibition) was entered at the first step, and simple inhibition (or spatial working memory) was entered at the second step. When group and spatial working memory were entered in the first step, inhibition was significantly related to the number of towers solved in minimum moves ($\beta = .39$, R^2 change $= .12$, $p < .001$), the number of towers correctly solved ($\beta = .39$, R^2 change $= .12$, $p < .001$), and the total number of moves ($\beta = -.31$, R^2 change $= .12$, $p < .001$). Conversely, spatial working memory was significantly related to all outcome measures when group and inhibition were entered on the first step (minimum number of moves, $\beta = .30$, R^2 change $= .08$, $p < .01$; total number of towers solved, $\beta = .22$, R^2 change $= .04$, $p < .05$; and total number of moves, $\beta = -.39$, R^2 change $= .08$, $p < .01$). This suggests that impairments in both spatial working memory and inhibition are necessary to account for the deficits in CANTAB-TOL performance observed in the PD patients relative to controls.

For the D-KEFS-TOH, simple inhibition was not significantly related to any of the outcome measures when entered at the second step (number of towers solved in minimum moves, $\beta = .14$, R^2 change $< .01$, $p < .25$; total number of towers solved, $\beta = .21$, R^2 change $< .03$, $p < .10$; and for the scaled score, $\beta = .15$ R^2 change $< .02$, $p < .25$). However, when group and inhibition were entered in the first step, spatial working memory was significantly related to D-KEFS-TOH performance in terms of the number of towers solved in minimum moves ($\beta = .51$, R^2 change $= .23$, $p < .001$), the number of towers correctly solved ($\beta = .37$, R^2 change $= .12$, $p < .01$) and the scaled score ($\beta = .47$, R^2 change $= .20$, $p < .001$). This suggests that spatial working memory is a stronger determinant of performance on the D-KEFS-TOH than simple inhibition.

TABLE 4
Correlation between Tower of Hanoi, Tower of London, Working Memory, and Inhibition Measures for Healthy Controls

	CANTAB-TOL			*D-KEFS-TOH*					
	(N) Solved in Min Moves	*(N) Correctly Solved*	*Total Number of Moves*	*(N) Solved in Min Moves*	*(N) Correctly Solved*	*Age-Adjusted Scaled Score*	*Spatial Span*	*Spatial Working Memory*	*Inhibition*
CANTAB- TOL[1]									
(N) Solved in min moves									
(N) correctly solved	**0.79*****								
Total number of moves[2]	**−0.89*****	**−0.87*****							
D-KEFS-TOH[3]									
(N) solved in min moves	**0.56*****	**0.57*****	**−0.61*****						
(N) correctly solved	0.28	**0.46****	**−0.34***	**0.54****					
Age adjusted scaled score	**0.36***	**0.52****	**−0.43****	**0.83*****	**0.83*****				
Working Memory Tasks									
Spatial Span	0.18	0.28	−0.28	0.25	0.12	0.21			
Spatial Working Memory[4]	**0.47****	**0.59*****	**−0.57*****	**0.62*****	**0.41***	**0.47****	−0.23		
Reading Span[5]	0.004	0.06	0.02	−0.09	0.05	0.01	0.18	−0.09	
D-KEFS Color Word[6]									
Inhibition	**0.38***	0.26	−0.27	0.09	0.02	0.06	**0.38***	−0.17	
Inhibition Switching	**0.43****	0.21	**−0.38***	0.10	−0.01	−0.10	0.11	−0.23	**0.41***

[1]Cambridge Automated Neuropsychological Test Battery-Stockings of Cambridge.
[2]Total average number of moves taken.
[3]Delis-Kaplan Executive Function System Tower Task.
[4]Scores for this task were inverted so that a higher score indicated good performance.
[5]Daneman and Carpenter Reading Span Task.
[6]Delis-Kaplan Executive Function System Color-Word Interference Task.
$^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

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DISCUSSION

The main objective of this study was to compare the relative sensitivity of the tower tasks from two well-established neuropsychological test batteries. To this end, we used the tower tasks from the CANTAB-TOL and the D-KEFS-TOH. In addition, measures of working memory and inhibition were also assessed. Compared with matched controls, medicated PD patients without dementia were impaired on the CANTAB-TOL but not the D-KEFS-TOH. PD patients also performed more poorly on measures of working memory and inhibition when compared with matched controls. Moderate correlations were obtained for PD patients between performance on the two tower tasks and with measures of working memory and inhibition. By contrast, for healthy controls, there was little association between performance on the tower tasks and measures of inhibition, and only one of the three working memory tasks was significantly related to performance on either of the tower tasks. Spatial working memory and inhibition were related to performance on the TOL task, but the contribution of inhibition to the TOH was much weaker. We confirmed this finding using regression analysis which showed that whereas performance on the CANTAB-TOL task was dependent on inhibition and spatial working memory, performance on the D-KEFS-TOH was dependent on spatial working memory only. These findings suggest that the CANTAB-TOL and the D-KEFS-TOH require different cognitive skills and should not be considered interchangeable measures for use with PD patients.

Our findings are consistent with previous research, using healthy younger participants, which reported that a significant amount of non-shared variance exists between the two tower tasks (Welsh et al., 1999). Further, previous research has also found evidence for the recruitment of different cognitive processes when solving the TOH compared to the TOL (Welsh, et al.; Zook, Davalos, DeLosh, & Davis, 2004). For example, Handley et al. (2002) reported that the TOH task correlated more with spatial memory capacity but not complex verbal working memory. Consistent with this finding, in the present study, D-KEFS-TOH performance was only correlated with visuospatial but not verbal aspects of working memory. Welsh et al. found that working memory and inhibition were strongly related to performance on the TOL task, but the contribution of inhibition to the TOH was much weaker.

The most obvious difference between these two tower tasks applied in the present study is that one is computerized while the other requires a manual presentation. It is possible that the method of administration in itself requires different cognitive resources, explaining the

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difference reported here. This problem is substantially overcome by using a healthy control group. However, the possibility remains that, due to reduced cognitive resources or difficulties with movement, the method of administration had more effect on the PD patients' ability to solve the tower problems.

Apart from the obvious physical structures of the two tower tasks, there are a number of possible reasons why these two tasks might vary in relation to the recruitment of cognitive processes. Firstly, the D-KEFS-TOH requires participants to plan for problems that require between one and 26 moves for perfect execution. On the other hand, the CANTAB-TOL task problem set only requires two to five moves. Although both tasks instruct the participant to plan moves prior to engaging in the task, it is likely that for many of the moves for the D-KEFS-TOH, participants engage in "online planning." That is, they plan moves while they are engaged in the task rather than planning all the moves before beginning the task. This is most likely because more complex problems in the TOH task are substantially based on recursive shuffling of discs (in contrast to the TOL), which would be difficult to plan out in full prior to beginning the task (Newell & Simon, 1972). Secondly, there may be floor effects associated with D-KEFS-TOH. Although problems are graded, with easier problems being presented first and more difficult ones later, problems move rapidly from those that nearly all participants can solve to problems in minimum moves to problems that only a few can solve, thus reducing the sensitivity of the task. Further, only one problem is presented at each level of difficulty, and there are no introductory problems. By contrast the CANTAB-TOL presents a number of introductory problems and more than one problem at each level.

On the other hand, the CANTAB-TOL uses the original set of problems as outlined by Shallice (1982), which are nested in the fact that earlier problems may form part of later problems. As a result, performance may depend to some extent on participants' learning across the problem set, and thus the CANTAB-TOL may not represent a test of pure planning ability. It has previously been reported that PD patients have problems with learning (Saint-Cyr, et al., 1988), even in the early stages of the disease (Buytenhuijs et al., 1994). Thus controls may benefit more from the nesting of CANTAB-TOL problems than PD patients. Using a problem set with repeatedly interspersed isomorphic color permutations of structurally unique TOL problems, Faber, Hinz, Botzel, and Danek (2007) recently found that PD patients did not improve across problem repetitions whereas age-matched healthy controls clearly benefited from implicit learning.

Some limitations of our study should be acknowledged. First, in terms of recruitment, approximately 30% of patients did not respond to the invitation to participate in the study which may have introduced a selection bias. We were unable to test this possibility because the study was designed so that patient details remained confidential until the individual agreed to participate. However, PD patients and controls were well matched in terms of age and premorbid IQ. To examine the performance on the tower tasks, we conducted a number of *t* tests to determine different areas of potential deficits. However, the resultant multiple analyses increased chance of Type I error. Another limitation was that many of the standard outcome measures associated with the D-KEFS-TOH were not directly comparable with those of the CANTAB-TOL, which constrained the degree to which we could contrast the two measures.

Berg and Byrd (2002) noted that the lack of consistency in findings between different tower tasks could be related to a number of issues including: 1) the actual differences in the tower structure; 2) insufficient attention to the difficulty of the problem set; and 3) variation in performance measures. Given these caveats, it is difficult to make direct comparisons between the D-KEFS-TOH and the CANTAB-TOL. Further, it seems likely that both present potential confounds in terms of the problem sets that are used (Unterrainer et al., 2005). Nevertheless the CANTAB-TOL was the more sensitive task as despite these potential problems it was still able to detect significant differences between the PD group and controls, in contrast to the D-KEFS-TOH. Future research should examine differences in tower structures, including the possible influence of manual and computerized tests on outcomes. Ideally these studies would also use a more structured approach to the selection of problem sets (McKinlay et al., 2008).

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