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Note

# Role of working memory components in planning performance of individuals with Parkinson's disease

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**Abstract**

The current study investigated the involvement of all four components of Baddeley's [Baddeley, A. D. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences*, *4*, 417–423] revised working memory model in deficits of planning accompanying Parkinson's disease (PD). PD resulted in poorer formulation and execution of plans, as measured by the Tower of London task. PD also reduced the efficiency of the episodic buffer and central executive components of working memory, but did not influence storage of verbal or visuospatial information. Planning deficits in PD were particularly linked to problems in integrating multimodal short-term information with long-term memory (episodic buffer). These results emphasize the importance of integrative and executive processing in cognitive problems in PD, rather than simple memory deficits.


*Keywords:* Parkinson's disease; Planning; Working memory; Tower of London (TOL)

In addition to motor symptoms, such as bradykineasia, rigidity and tremor, many patients with Parkinson's disease (PD) suffer from cognitive deficits. The cognitive deficits of newly diagnosed patients with PD resemble those observed following frontal lobe damage: difficulties with executive functions like task set switching, inhibition and problem solving (Lewis et al., 2003; Uekermann et al., 2004). For instance, patients with PD exhibit planning deficits on the Tower of London task (TOL, Shallice, 1982), which requires forward planning and subsequent execution of a sequence of moves. Patients with PD show poorer accuracy of planning, particularly in unmedicated states (Cools, Barker, Sahakian, & Robbins, 2001; Morris et al., 1988; Owen et al., 1995). Dopaminergic medication may improve planning through increased prefrontal blood flow (Cools et al., 2001).

Working memory deficits have often been argued to underlie cognitive deficits in PD (Lewis et al., 2003; Morris et al., 1988; Owen et al., 1995). Kliegel, Phillips, Lemke, and Kopp (2005) report that PD effects on a task involving planning overlapped with differences in working memory capacity. The term working memory describes a dynamic cognitive system which stores and processes information simultaneously. One influential way of conceptualising working memory is the three component system (Baddeley & Hitch, 1974) comprising a phonological loop to maintain verbal information, a sketchpad to maintain visuospatial information (Baddeley, 1986), and a central executive attentional system which coordinates the two maintenance systems by updating the storage buffers when new relevant information is available (Baddeley, 2003; Shallice, 2002). Recently, a fourth component was added, the episodic buffer, which integrates information from different modalities and provides an interface between the sub-systems and long-term memory (Baddeley, 2000, 2003).

In healthy adults, each of these working memory components has been linked to the TOL planning task. Dual task studies (Phillips, Wynn, Gilhooly, Della Sala, & Logie, 1999) indicate that the visuospatial buffer is important in constructing and re-formulating plans, while the central executive is likely to be involved in monitoring goal achievements, and switching attention between the actual state of the disks and imagined

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representations. The articulatory loop supports verbally generated mental plans. No research has directly investigated the role of the episodic buffer, but it is likely to be important because the TOL requires the formation of strategic information in long-term memory and its subsequent retrieval.

PD patients have previously been found to show reduced performance in visuospatial (e.g., block span, Kemps, Szmalec, Vandierendonck, & Crevits, 2005) and verbal working memory (e.g., word span, Fournet, Moreaud, Roulin, Naegele, & Pellat, 2000, however, findings with respect to digit span are mixed, e.g., Muller, Wachter, Barthel, Reuter, & von Cramon, 2000). PD also results in deficits of executive functioning (e.g., Uekermann et al., 2004; Weintraub et al., 2005) and episodic memory (e.g., logical memory, Lee, Chan, Ho, & Li, 2005; Muller et al., 2000). It is therefore plausible that any of the four components of working memory might influence the planning problems found in PD patients. Thus, applying an individual differences approach, the present study investigates which components of working memory might be implicated in problems with planning in patients with PD.

## 1. Method

### 1.1. Participants

The participants in the current study were 16 patients with Parkinson's disease ($M_{\text{age}}=61.1$ years; S.D. = 6.9 and $M_{\text{disease duration}}=4.81$ years; S.D. = 3.0) and 16 age-matched healthy controls ($M_{\text{age}}=62.6$ years; S.D. = 9.1). Five patients and eight controls were women. All participants were right-handed as assessed with the Edinburgh Handedness Inventory (Oldfield, 1971), and had no other history of psychiatric, neurological or cardiovascular diseases, or substance abuse. No participants with depression (exclusion criterion, Beck Depression Inventory (BDI) > 10) or dementia (exclusion criterion, Mini Mental State Examination (MMSE) < 24) were included.

Ten PD patients were Hoehn and Yahr stage 1 (Hoehn & Yahr, 1967) and six were stage 2. Of those in stage 1, half showed right and half left unilateral symptoms. On the Unified Parkinson Disease Rating Scale (UPDRS, Fahn & Elton, 1987) patients were mildly affected (range = 5–25; $M=13.83$, S.D. = 6.01). BDI, MMSE and Hoehn and Yahr were carried out no more than two weeks before experimental testing. The UPDRS was conducted at a medical check within 4 months of the testing session. Fifteen patients took both L-dopa and pergolide, while one took pergolide only ($M_{\text{dose L-dopa}}=417.33$ mg/day, S.D. = 145.43; $M_{\text{dose pergolide}}=4.75$ mg/day, S.D. = 1.7). Due to a 'wearing off' phenomenon two patients took entacapone. No patient took anticholinergic drugs and for no patient an 'on-off' phenomenon was reported. For at least 12 h before testing, antiparkinson medication was discontinued.

### 1.2. Apparatus

To assess *planning* ability a computerised Tower of London (TOL, Shallice, 1982) was administered. Three different-coloured disks were displayed on three rods that varied in size. Participants were instructed to achieve the end state in the fewest moves possible while following specific rules: a smaller disc could not be placed on a bigger one, and only one disk could be moved at a time. The main dependent variable was the number of moves (minimum = 50) in which the 10 given problems were solved. More moves indicate worse planning performance.

The *phonological loop* was assessed with the digit span forward subscale of the Wechsler Adult Intelligence Scale (WAIS-R, Tewes, Neubauer, & von Aster, 2004, for application as a measure of the phonological loop see, e.g., Walley & Donaldson, 2005). This test consisted of sequences of numbers of different length (ranging from 3 to 9 digits, two sequences of each length); each read out by the experimenter and then repeated by the participant. One point is given for each correct sequence.

To determine the performance of the *visuospatial sketchpad* the block span forward subtest of the Wechsler Memory Scale (WMS-R, Härting et al., 2000, for application as an indicator for the visuospatial sketchpad see, e.g., Baddeley, 1986; Pickering, 2001) was applied. Participants were shown visual sequences of blocks (ranging from 2 to 8 items, two sequences of each length) and asked to repeat them. One point is given for each correctly reproduced block series.

The logical memory subtest of the Wechsler Memory Scale was administered to assess the *episodic buffer* (WMS-R, Härting et al. (2000), for application as an indicator for the episodic buffer see, e.g., Baddeley & Wilson, 2002). Participants were read two short stories and immediately asked to retell them. The number of ideas recalled was assessed.

As a measurement of *central executive* processes an *n*-back task was employed (for application as indicator for central executive functioning see, e.g., Cicerone, 2002; Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001). A verbal two-back paradigm was used: 200 consonants, were presented one at a time on a PC screen for 200 ms, with an interstimulus interval of 2500 ms. Participants had to indicate whether each present stimulus was equal to that seen two screens before. The dependent variable was the overall number of correct responses.

### 1.3. Procedure

Only those participants who had given informed consent took part in the study. Tests were administered in the following order: digit span, block span, logical memory, *n*-back task and the Tower of London.

## 2. Results

### 2.1. Group differences

All variables were normally distributed and variances were homogenous. Analyses of variance (ANOVAs) were conducted to evaluate group differences in age, education (PD: $M=11.0$ years, S.D. = 2.4; controls: $M=11.4$ years, S.D. = 1.7; $F(1,29)=0.36$) and verbal intelligence (Mehrfachwahlwortschatztest [Multiple Choice Vocabulary Test], Lehrl, Merz, and Burkhard (1991): PD: $M=113.3$, S.D. = 13.5,

Table 1
Group differences in planning and working memory components

| | PD patients, *M* (S.D.) | Control group, *M* (S.D.) | *F* | *p* | *d* |
|---|---|---|---|---|---|
| Planning | | | | | |
| Tower of London: number of moves | 59.36 (3.49) | 55.81 (4.9) | $F(1,28) = 4.98$ | $\leq 0.017$ | 0.84 |
| Phonological loop | | | | | |
| Digit span | 7.4 (1.8) | 7.3 (2.1) | $F(1,29) = 0.015$ | $\leq 0.451$ | 0.05 |
| Visuo-spatial sketchpad | | | | | |
| Block span | 6.9 (1.8) | 7.8 (1.6) | $F(1,29) = 2.39$ | $\leq 0.067$ | 0.53 |
| Episodic buffer | | | | | |
| Story recall | 10.54 (3.7) | 13.12 (2.8) | $F(1,27) = 4.64$ | $\leq 0.020$ | 0.80 |
| Central executive | | | | | |
| *n*-Back | 126.83 (32.29) | 158.27 (28.17) | $F(1,25) = 11.73$ | $\leq 0.001$ | 1.04 |

Table 2a
Planning performance on the TOL comparing PD patients with controls who have low and high performance on the episodic buffer (EB) component of working memory

| | PD patients, *M* (S.D.) | Controls low EB, *M* (S.D.) | Controls high EB, *M* (S.D.) | *F* | *p* |
|---|---|---|---|---|---|
| Tower of London: number of moves | 59.36 (3.49) | 57.87 (5.11) | 53.75 (4.09) | $F(2,27) = 4.75$ | $\leq 0.009$ |

Table 2b
Planning performance on the TOL comparing PD patients with controls who have low and high performance on the central executive (CE) component of working memory

| | PD patients, *M* (S.D.) | Controls low CE, *M* (S.D.) | Controls high CE, *M* (S.D.) | *F* | *p* |
|---|---|---|---|---|---|
| Tower of London: number of moves | 59.36 (3.49) | 56.71 (4.31) | 55.88 (5.59) | $F(2,26) = 1.96$ | $\leq 0.081$ |

controls: $M = 118.6$, S.D. = 13.8, $F(1,30) = 1.22$) and no group effects were observed.[1] ANOVAs showed that laterality of symptoms did not affect patients' performance in any test.

To investigate group differences in planning and working memory performance ANOVAs were conducted (see Table 1).[2] As all predictions were of patient deficits, one-tailed tests were used, but with Bonferroni correction (considering the intercorrelation of the tests, mean $r = 0.283$, see Sankoh, Huque, and Dubey (1997), the corrected alpha level for each test is 0.02 to get an overall alpha level of 0.05). A large-sized group difference emerged in planning, with controls taking fewer moves on the TOL. For working memory components, there were no group differences on phonological loop or visuospatial sketchpad measures. There was a significant large-sized PD group deficit on the episodic buffer and central executive tasks (as measured by Cohen's *d*, Cohen, 1988).

### 2.2. Decomposing the planning deficit

In a second step, controls were median-split according to their performance on central executive and episodic buffer measures following an analytical approach previously used, e.g., by Moritz and Woodward (2006). The logic here is that if PD deficits in TOL are linked to deficient performance in a specific working memory component, their TOL scores should match controls who have low scores on that component. PD patients' TOL performance was first compared to controls with low versus high episodic buffer performance. Results (in Table 2a) indicate a significant group effect when subdividing controls according to their episodic buffer performance. Post hoc analyses (Scheffe) revealed significant differences between patients and high-performing controls ($p < 0.018$). A similar analysis using central executive scores did not result in a significant group effect (see Table 2b). In addition, corroborating those results, significant differences between low and high episodic buffer controls ($p < 0.05$) were found, however, not between low and high central executive controls on the TOL.

## 3. Discussion

Current results replicate previous findings of TOL planning deficits in PD patients (Cools et al., 2001; Morris et al., 1988; Owen et al., 1995). We also extended these findings by investigating the role of all four components of the recently revised working memory model (Baddeley, 2000, 2003) in

[1] A reviewer suggested using age-corrected normative scores or covarying age in the following analyses. This, however, did not change results.

[2] Degrees of freedom vary due to four patients having partly incomplete data. To work with the fullest possible power, statistical analyses were conducted with all available data. Nevertheless, we have carried out additional analysis on the reduced sample with complete data on all neuropsychological tests and the pattern remains. With exception of the *n*-back task, all tests were statistically insignificant due to the small power in the reduced sample (power ranging between 0.07 and 0.35; cf. the power of 0.88 of the *n*-back task). However, all *F* values were larger than 2.5 for the tests that differed significantly in the original sample.

these planning deficits. While PD patients were not affected in verbal or visuospatial buffer functioning, they showed reduced central executive and episodic buffer efficiency.

Comparisons of median-split controls with patients indicate an involvement of the episodic buffer in planning performance. Controls with low episodic buffer performance showed a similar planning ability as PD patients, whereas controls with high episodic buffer scores showed higher TOL performance. No group differences were found when splitting the control sample by median executive performance. These results suggest that the poorer planning of PD patients is not linked to declines in the ability to maintain verbal or spatial information or executive dysfunction, but instead appear to reflect problems in integrating short-term codes with long-term memory (i.e., problems associated with the episodic buffer; Baddeley, 2003). These results suggest a potential relationship between reduced performance in a specific working memory component and planning problems in PD.

A limitation of this study is that the episodic buffer and executive measures focus on verbal rather than visuospatial information and that each of the individual difference measures used is likely to involve to some degree more than one component of working memory. In addition, optimal assessment of the episodic buffer is still under debate (e.g., Gooding, Isaac, & Mayes, 2005) and the test applied mainly focuses on the long-term memory interface aspect of the episodic buffer. Thus, it would be useful in future studies to corroborate the current findings using experimental manipulations of a planning task, which vary the involvement of different working memory components. In addition, future studies need to rule out further explanations for patients' logical memory performance, such as a long-term memory deficit similarly to that of patients with organic amnesia (Isaac & Mayes, 1999); which is consistent with evidence of a medial temporal involvement in PD (Cordato, Halliday, Harding, Hely, & Morris, 2000).

The current results fit in with previous studies indicating that working memory may be implicated in the effects of PD on tasks involving planning (Cools et al., 2001; Morris et al., 1988; Owen et al., 1995). It would be useful in future research to investigate the extent to which changes in specific aspects of working memory might underlie a range of cognitive deficits in PD. Indications from the current study are that it may be particularly important to explore the role of central executive and episodic buffer components of working memory, rather than concentrating on indicators of memory storage in verbal or visual modalities.

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