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Note

Planning in Parkinson's disease: A matter of problem structure?

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Abstract

Although the Tower of London (TOL) has been extensively used to assess planning ability in patients with Parkinson's disease (PD), the reported presence or extent of any planning deficits has been inconsistent. This may partly be due to the heterogeneity of the TOL tasks used and a failure to consider how structural problem parameters may affect task complexity. In the present study, planning in PD patients was assessed by systematically manipulating TOL problem structure. Results clearly disprove the identity assumption of problems with an equal number of minimum moves. Instead, substantial parts of planning performance were related to more subtle aspects of problem structure, such as subgoaling patterns and goal hierarchy. Planning in PD patients was not impaired in general but was affected when the information provided by the problem states was ambiguous in terms of the sequential order of subgoals, but not by increases in search depth.

Keywords: Parkinson's disease; Tower of London; Planning; Problem structure

1. Introduction

In addition to its well-known motor symptoms, Parkinson's disease (PD) is associated with a number of cognitive deficits, including planning. To plan successfully, an individual must look ahead through a series of possible steps, some of which may be counterintuitive, to reach a desired goal. The ability to plan is an essential part of daily living, and difficulties with this skill may negatively affect autonomy and quality of life. Planning deficits in PD have been found even in the early stages of the disease process (Culbertson, Moberg, Duda, Stern, & Weintraub, 2004; Hodgson, Tiesman, Owen, & Kennard, 2002; Morris et al., 1988; Owen et al., 1992; Taylor, Saint-Cyr, & Lang, 1986), and may reflect the fronto-striatal circuit degeneration associated with this disorder (Owen, 2004). One of the most common tasks used to measure planning ability in PD is the Tower of London (TOL; Shallice, 1982). However, the literature is inconsistent with regard to the presence or exact nature of any planning deficits in PD, possibly reflecting the variation of TOL tasks applied.[2] Further, non-uniform procedures and problem sets have been used, making it difficult to compare results across studies. To effectively assess planning deficits in PD a more systematic consideration of these issues is required (Taylor & Saint-Cyr, 1995).

Abbreviations: PD, Parkinson's disease; TOL, Tower of London; NART, National Adult Reading Test; MMSE, Mini Mental Status Exam; DRS-2, Dementia Rating Scale; BDI-II, Beck Depression Inventory-II; DSM-IV, Diagnostic and Statistical Manual of Mental Disorders-IV; UPDRS, Unified Parkinson's Disease Rating Scale

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[2] For instance, Culbertson et al. (2004) reported a group of PD patients performing significantly worse than controls in terms of average number of moves, while Morris et al. (1988) previously found no differences in accuracy but only for planning times.

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Recent research has emphasized the selection of specific tower problems because it has been suggested that different aspects of individual problems may increase or decrease the level of task complexity, and therefore the cognitive demands for planning (Berg & Byrd, 2002). At the most basic level, the minimum number of moves can be viewed as an indication of how difficult a particular problem is. However, difficulty may be influenced by more than just the number of moves required for solution. For example, problems with the same number of moves may have a different search depth or subgoaling pattern. A subgoal move refers to moves that are essential to the solution of a given problem, but do not place the ball into its goal position (Ward & Allport, 1997). Search depth is defined as the number of subgoal moves before the first ball can be placed into a goal space (Spitz, Webster, & Borys, 1982). In TOL problems, search depth is related to mainly two predominant subgoaling patterns (Kaller, Unterrainer, Rahm, & Halsband, 2004). Specifically, optimal solutions of five-move problems either require (1) sequences of two initial subgoal moves followed by three goal moves; or (2) sequences of a subgoal move followed by a goal move, another subgoal move, and two final goal moves (Fig. 1A). As a result, five-move TOL problems feature search depths of either two or one initial subgoal moves, respectively.

Goal hierarchy is another aspect of problem structure that affects task complexity (Klahr & Robinson, 1981; Ward & Allport, 1997). Goal hierarchy is related to the ambiguity of information on subgoal ordering, that is, the degree to which the sequence of the final goal moves can be derived from the configuration of the goal state (Kaller et al., 2004). For example, problems with "tower" goal states, where all three balls are

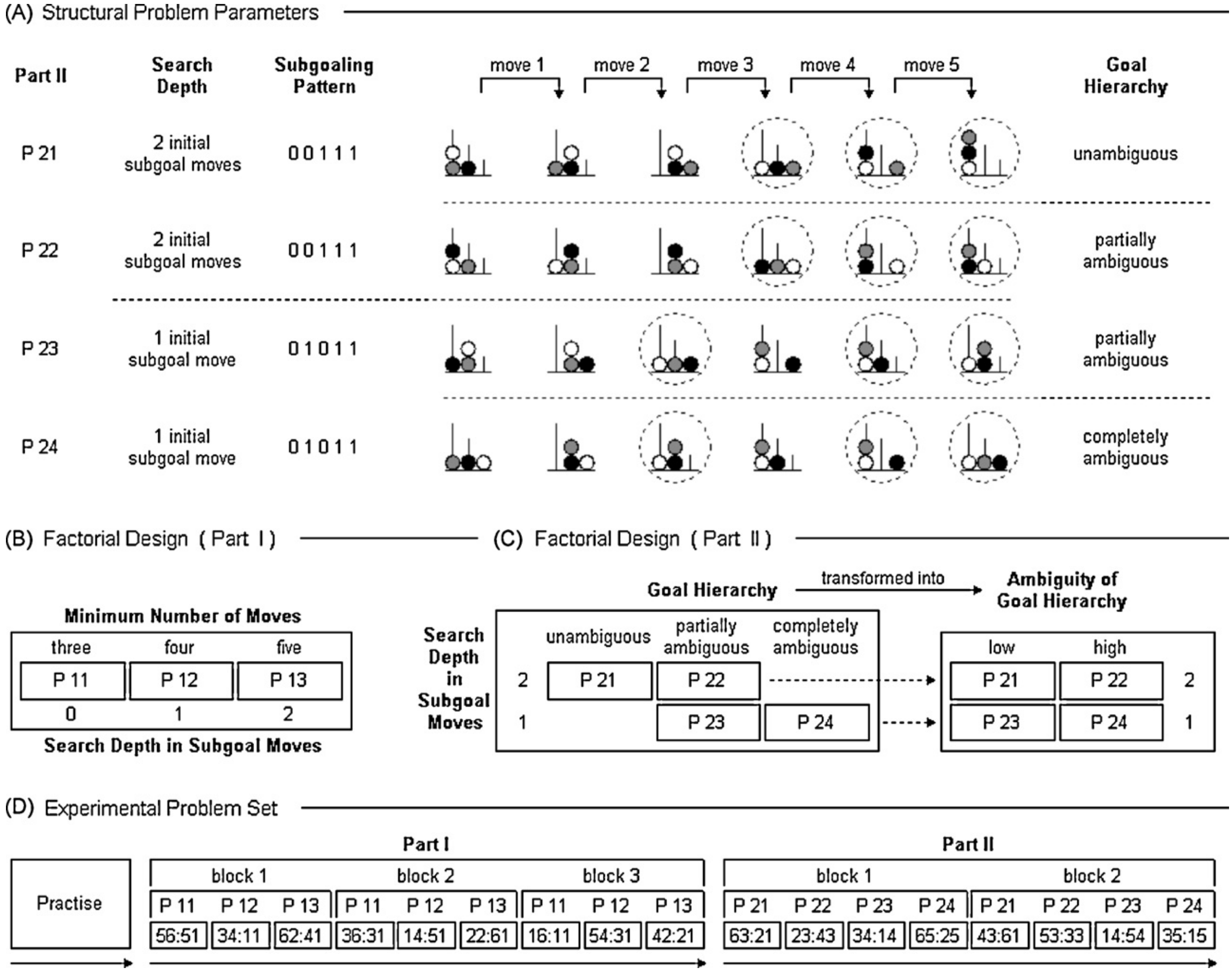

Fig. 1. (A) Structural problem parameters. Illustrations of goal hierarchy and search depth are exemplified on five-move TOL problems that were applied in Part II of the experiment. Four different types of problems were administered (P21–P24). In the TOL, two predominant subgoaling patterns are evident causing "search depths" of either one (P23, P24) or two initial subgoal moves (P21, P22). Goal hierarchy relates to the three possible configurations of the goal state: "tower" (P21), "partial tower" (P22, P23), and "flat" structures (P24) differentially predispose the consecutive order of the final goal moves and the associated subgoal sequences. Goal moves and subgoal moves are indicated by digits '1' and '0', respectively. Dashed circles around problem states denote goal moves. (B) Factorial design (Part I). For the assessment of general planning ability, search depth was step-wise increased in combination with the minimum number of moves (P11–P13). Goal hierarchy was kept unambiguous by using only goal states with "tower" structures. Problems featured only one optimal path to solution and no suboptimal alternatives. (C) Factorial design (Part II). In the second part, the influence of goal hierarchy and search depth on planning performance was systematically manipulated in a set of five-move problems (P21–P24) while controlling for other influences of problem structure. (D) Experimental problem set. Numbers in boxes at the bottom denote start state and goal state of presented problems in the notation suggested by Berg and Byrd (2002).

stacked on a single rod, provide an unambiguous goal hierarchy because the ball at the bottom has to be placed in its goal position before the ball that is second from the bottom, and so on. By contrast, no such information can be derived from "flat" goal states (Fig. 1A). Problems may also vary concerning the number of optimal paths to solution which refer to the number of different possible solutions that allow the problems to be solved in the minimum number of moves (Newman & Pittman, 2007; Unterrainer, Rahm, Halsband, & Kaller, 2005). In addition, there may also be suboptimal alternatives that take more than the minimum number of moves, but allow the first ball to be placed into its goal position within a number of moves equal to the optimal solution (Kaller et al., 2004).

Given the variety of the aforementioned aspects of problem structure, it seems plausible to assume that systematic manipulations of TOL problem parameters will have differentiable effects on planning performance, in particular with respect to clinical populations that are known to have planning impairments. The aims of the present study are hence two-fold. First, we wanted to test the widespread assumption of identical task complexity for problems with an equal number of minimum moves. The apparent popularity of this assumption seems to be implicated to some extent by the large number of studies using minimum moves as the only indicator of problem difficulty, without any consideration of other structural problem parameters. Our second goal was to test the hypothesis that planning ability of PD patients is more severely affected in problems that, irrespective of the minimum number of moves, have higher demands on active manipulation of spatial information within working memory and identification and implementation of organizational strategies (Cools, 2006; Owen, 2004). Thus, in the present study we examined the effects of systematic manipulations of problem structure in terms of goal hierarchy and search depth.

2. Methods

2.1. Subjects

The study was approved by the local ethics committee and all subjects gave written consent prior to participation. Participants were recruited from a data base of PD patients and healthy controls. Thirty non-demented and non-depressed patients with idiopathic PD diagnosed by a neurologist who specialized in movement disorders were assessed (see Table 1 for inclusion/exclusion criteria). All patients were on anti-Parkinsonian medication and were tested while on optimal levels. Thirty healthy controls were individually matched in terms of age and pre-morbid intelligence.

Assessments were carried out at the University of Canterbury over two testing sessions. Tests were presented in a fixed order with breaks taken as required. Planning ability was assessed using the TOL at the beginning of the second session.

2.2. Demographic and clinical information

Pre-morbid intelligence was estimated using the National Adult Reading Test (NART; Nelson & Willison, 1991). Current cognitive status was examined by the Mini Mental Status Exam (MMSE, Folstein, Folstein, & McHugh, 1975) and the Dementia Rating Scale (DRS-2; Jurica, Leitten, & Mattis, 2001). The Beck Depression Inventory-II (BDI-II; Beck, Steer, & Brown, 1996) was applied as a measure of affective disturbances. In addition to the Hoehn and Yahr (1967), severity of motor impairment was assessed the Unified Parkinson's Disease Rating Scale (UPDRS; Fahn & Elton, 1987). Demographic and clinical characteristics for PD patients vs. healthy controls are shown in Table 2.

Table 1
Inclusion and exclusion criteria

Inclusion criteria
- Diagnosis of idiopathic Parkinson's disease, assessed as between Hoehn and Yahr (1967) stage I–III
- Aged between 50 and 80 years, English as the primary spoken language, adequate or corrected hearing and vision (self-report checked by examiner)

Exclusion criteria
- History of moderate or severe head injury, stroke or other neurological impairment, major medical illness, psychiatric illness requiring hospitalisation
- Currently involved in a therapeutic trial
- Suspicion of dementia (MMSE < 25), diagnosis of learning disability, pre-morbid IQ < 85 (NART)
- Acute depression or major depressive episode in the previous six months (BDI-II > 17; DSM IV)
- Taking other than anti-Parkinsonian medication known to have significant effects on the central nervous system

The same criteria were also applied for the selection of healthy controls with the exception of issues related to diagnosis and medical treatment of PD.

Although there were significant differences between the two groups in terms of mood ratings (BDI-II) and cognitive status (MMSE, DRS-2), none of the PD patients showed any evidence of clinical depression or dementia (cf. Table 1).

2.3. Planning task and instructions

A computerized version of the TOL was used to assess planning ability. Start and goal states were presented in the lower and upper half of the screen, respectively. Subjects were instructed to transform the start state into the goal state while following three rules: (1) only one ball may be moved at a time; (2) a ball cannot be moved while another is lying on top of it; and (3) three balls may be placed on the tallest rod, two balls on the middle rod, and one ball on the shortest rod. Subjects were instructed to solve each problem in the minimum number of moves (indicated on the screen). To match the goal state, subjects had to operate on the start state. Movements were executed on an ELO 17″ touch sensitive screen. Individual trials were initiated by the experimenter. Before displaying the next problem, subjects were prompted by the program to plan ahead first. Prior to the experimental trials, subjects were familiarized with

Table 2
Sample descriptions in terms of demographic and clinical information

	Controls *M* (S.D.)	PD *M* (S.D.)	*t*-Value	*p*-Value
Age	66.43 (5.3)	65.77 (6.6)	0.43	>0.65
EDU	13.78 (2.7)	14.08 (2.8)	0.42	>0.65
NART	111.67 (10.8)	109.93 (10.8)	0.70	>0.45
MMSE	29.70 (0.5)	28.90 (1.2)	3.44	<0.01
DRS-2	12.07 (2.6)	10.60 (1.8)	2.52	<0.05
BDI-II	3.33 (2.6)	8.60 (3.8)	5.29	<0.001
PD-Ons		58.5 (8.8)		
PD-Dur	–	7.3 (4.6)	–	–
H&Y	–	2.30 (0.6)	–	–
UPDRS	–	27.13 (7.5)	–	–

Numbers in parentheses denote the standard deviation. *Abbreviations*: EDU—total years of education; PD-Ons—age of diagnosis/PD onset (in years); PD-Dur—duration of disease (in years). For the remaining abbreviations, please refer to Section 2.

the TOL and the handling of the touch screen in a practice phase using two- and three-move problems.

2.4. *Experimental design*

The assessment of planning ability occurred in two parts. The objective of Part I was to examine whether planning in PD was generally impaired even in highly structured and well-defined situations. Therefore, the minimum number of moves was systematically increased from three to five moves while problems featured only a totally unambiguous goal hierarchy. This enabled, search depth, but no other confound, to be varied systematically (together with minimum number of moves) from zero to two initial subgoal moves before the first goal move (Fig. 1B). In addition, problems had only one optimal path for solution but no suboptimal alternatives.

A more complex scenario was examined in Part II by systematically varying search depth and goal hierarchy in a set of five-move problems (Fig. 1A and C). In contrast to Part I, the applied problems also featured alternative paths leading to suboptimal solutions. The minimum number of five moves for these TOL problems could only be achieved by one optimal path for solution. The specific aim of Part II was hence to disentangle the contributions of two specific aspects of problem structure, that is, search depth and goal hierarchy, to planning impairments in PD patients, while the minimum number of moves was kept constant.

The factorial designs of both Part I and II are illustrated in Fig. 1B and C, respectively. Due to general features of the TOL problem space, the combination of both search depth and goal hierarchy in Part II inevitably results in an imbalanced design since certain problem configurations do simply not exist. Testing for possible interactions between goal hierarchy and search depth would therefore be unfeasible (Winer, 1962). However, to allow for an factorial analysis of the interesting main effects and interactions with group, the composition of the two structural problem parameters was hence transformed into a hierarchical design by nesting the relative ambiguity of subgoal ordering, i.e., goal hierarchy, under the levels of search depth (Fig. 1C). The resulting problem set is shown in Fig. 1D. Within Parts I and II, problems were presented block-wise using a fixed order within blocks. Across blocks, different isoforms of problems were applied using pseudo-randomized permutation of ball colours. More detailed information on the selection of structurally unique problems and the balancing of isoforms (Berg & Byrd, 2002) can be obtained from the corresponding authors.

2.5. *Measures*

For the analyses reported below, accuracy of problem solutions was recorded. The terms ‘performance’ and ‘accuracy’ are henceforth used interchangeably and refer to the percentage of problems correctly solved in the minimum number of moves.

Table 3

Part I—Mean percent of TOL problems correctly solved, listed separately for the PD and control group

Part I	Three moves	Four moves	Five moves
Controls	100.0% (0)	92.3% (3.1)	94.4% (3.2)
PD	98.9% (1.1)	93.4% (3.7)	91.2% (3.9)

Numbers in parentheses denote the standard error of mean.

3. Results

3.1. *Part I*

Performance in the first part of the experiment was almost at ceiling for both healthy controls and PD patients (Table 3). A two-way repeated-measures ANOVA on accuracy revealed a significant main effect for the minimum number of moves [$F(2,58) = 6.81$, $p = 0.002$, $\eta^2 = 0.105$], but no main effect for group [$F(1,58) = 0.11$, $p = 0.742$, $\eta^2 = 0.002$] or interaction between factors [$F(2,58) = 0.55$, $p = 0.577$, $\eta^2 = 0.009$]. Post hoc pair-wise comparisons yielded significant differences between three-move problems and four- as well as five-move problems ($p < 0.005$) but performance in four- and five-move problems proved to be equally difficult ($p = 0.993$).

3.2. *Part II*

As is evident from Fig. 2, performance in five-move problems could be systematically attributed to the experimental manipulations of problem structure. A three-way repeated-measures ANOVA on accuracy yielded significant main effects for search depth [$F(1,58) = 22.31$, $p < 0.001$, $\eta^2 = 0.278$] and goal hierarchy [$F(1,58) = 9.12$, $p = 0.004$, $\eta^2 = 0.137$] but not for group [$F(1,58) = 0.53$, $p = 0.472$, $\eta^2 = 0.009$]. In addition, the interaction between group and goal hierarchy was significant

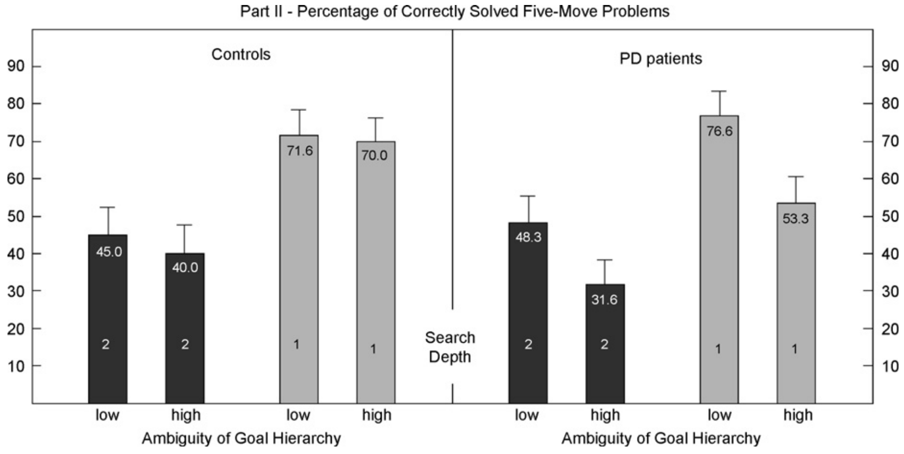

Fig. 2. Part II—Mean performance in percent, plotted separately for the PD group vs. healthy controls and according to the experimental manipulation of problem structure, that is, search depth and ambiguity of goal hierarchy. The latter parameter is arranged on the abscissa, while the former is illustrated using bar colours gray and black for search depths of one and two initial subgoal moves, respectively. Note that in Part II, all problems had an equal minimum number of five moves for optimal solution. Error bars denote the standard error of mean.

[$F(2,58) = 4.70$, $p = 0.034$, $\eta^2 = 0.075$]. Post hoc analyses confirmed a highly significant effect of goal hierarchy in the PD group ($p < 0.001$) but not for controls ($p = 0.580$). That is, planning performance of PD patients was, in contrast to healthy controls, specifically affected by increased ambiguity of goal hierarchy. None of the remaining interactions was found to reach statistical significance [all $F(1,58) < 0.5$, $p > 0.5$, $\eta^2 < 0.01$].

To preclude that a possibly existing interaction between search depth and group had been simply masked due to the interleaved shifting of goal hierarchy within the nested design, an additional two-way repeated-measures ANOVA was conducted on search depth (cells P22 and P23, Fig. 1C) and group. That is, the effects of search depth and group were directly tested in those problems that featured a partially ambiguous goal hierarchy. In line with the analysis reported above, results again revealed a significant main effect solely for search depth [$F(1,58) = 27.77$, $p < 0.001$, $\eta^2 = 0.324$], but neither a main effect of group [$F(1,58) = 0.07$, $p = 0.800$, $\eta^2 = 0.001$] nor an interaction [$F(1,58) = 0.84$, $p = 0.363$, $\eta^2 = 0.014$].

4. Discussion

The results of this study revealed that planning in PD patients was generally intact when the ambiguity of the planning situation was reduced to a minimum (Part I). In such cases, PD patients correctly solved even five-move problems with an accuracy of greater than 90%. However, we also found that planning performance of PD patients substantially declined if the ambiguity of goal hierarchy was increased (Part II). That is, compared to normal controls, PD patients exhibited a discernable planning deficit only in those problems with less predictable subgoal sequences.

With respect to the first aim of this study, our results strongly challenge the wide-spread assumption that problems with an equal minimum number of moves also feature an identical level of task difficulty. Instead, the present results suggest that problems with an equal minimum number of moves do not necessarily have to share identical task difficulty (*within-level variability*), nor does a gradual increase of minimum moves necessarily imply a correlated rise of task difficulty (*between-level invariability*). This conclusion is supported by previous research on the psychometric properties of the TOL (Culbertson et al., 2004; Humes, Welsh, Retzlaff, & Cookson, 1997; Kafer & Hunter, 1997; Schnirman, Welsh, & Retzlaff, 1998) as well as by studies explicitly addressing the impact of problem structure on planning (Carder, Handley, & Perfect, 2004; Kaller et al., 2004; Newman & Pittman, 2007; Unterrainer et al., 2005; Ward & Allport, 1997).

As for the second aim of this study, planning performance of PD patients was indeed specifically associated with systematic manipulations of structural problem parameters (Part II). PD patients were not impaired in general but only affected when the information provided by the goal state was ambiguous with respect to the sequential order of subgoals. PD patients were, however, no more liable to increases in search depth than healthy controls (Fig. 2). These results are particularly pertinent in the light of a recently proposed framework on the distinct roles that are played by the striatum and the prefrontal cortex in the flexibility and stability of cognitive representation, respectively (Cools, 2006). Given a prevalence of dopamine depletion particularly in the dorsal striatum, PD patients with mild to moderate symptoms are supposed to exhibit a dissociable pattern of impaired active reorganization and manipulation of working memory contents, while maintenance of information is preserved (Owen, 2004). These opposing predictions seem to be also reflected in the present results because a PD-specific deficit was observed for TOL problems with higher ambiguous goal hierarchy but not for increases in search depth. Goal hierarchy affects the “degrees of freedom” of the planning situation by more or less explicitly determining the sequential order of single steps on the solution path (Kaller et al., 2004; Ward & Allport, 1997). Higher ambiguity of goal hierarchy should therefore be associated with increasing demands on cognitive flexibility, that is, the active implementation of organizational strategies in order to search and generate the optimal sequence of moves (Cools, 2006; Owen, 2004). Thus, in the absence of direct guidelines that are explicitly provided by the configuration of the goal states, PD patients would consequently be expected to exhibit less efficient planning abilities (see also Taylor & Saint-Cyr, 1995), as was observed in the present study. In contrast, given a likely “anchoring” function of the first goal move and the chunking of subgoal-move sequences (Ward & Allport, 1997), increases of search depth might primarily relate to aspects of working memory maintenance. Because working memory is generally not affected in mild to moderate stages of the disease (Owen et al., 1992), PD patients would accordingly not be expected to show any specific planning deficits in problems with larger search depths, which is again consistent with the present results. However, increases in search depth are, at least to some extent, also associated with higher demands on strategic look-ahead (Spitz et al., 1982) that, unlike the present study, might cause a PD-related decline in accuracy. Likewise, accomplishing suboptimal alternatives might also increase demands on cognitive flexibility as misleading paths, if recognized, have to be circumvented by searching an optimal solution. Present data,[3] however, do not suggest such an association. Instead, subjects did not necessarily become aware of when they had chosen a suboptimal path. As the minimum number of moves was indicated, PD patients as well as healthy controls have most likely not planned ahead complete solutions but seemingly started instead to execute already after having found a partial solution path towards a first goal move, which in problems with suboptimal alternatives could have been also misleading. Thus, it rather seems that increased problem difficulty due to suboptimal alternatives might be mainly related to other processes such as, for instance, to successfully inhibit a premature selection of inappropriate

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[3] A comparison of five-move problems with an unambiguous goal hierarchy and search depths of two intermediate moves across Parts I and II (P13 and P21, see Fig. 1B and C) allows to estimate the impact of suboptimal alternatives on planning performance. Results revealed a highly significant effect of suboptimal alternatives [$F(1,58) = 90.48$, $p < .001$, $\eta^2 = .609$] which was, however, entirely independent of group [$F(1,58) = 1.19$, $p = .280$, $\eta^2 = .020$] or any interactions with group [$F(1,58) = .18$, $p = .674$, $\eta^2 = .003$].

moves (Carder et al., 2004). Future research should therefore address these issues in particular.

Taken together, systematic manipulations of TOL problem structure in the present study provided clear evidence that detection of planning deficits in PD patients is dependent on the cognitive demands of the specific problems employed in the task. Given the wide-spread use of the TOL and other related disc-transfer tasks as assessment tools in clinical and research contexts, more attention should be paid to the effects of problem structure.

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References

Beck, A. T., Steer, R. A., & Brown, G. K. (1996). *Beck depression inventory* (2nd ed.). New York: The Psychological Corporation.

Berg, W. K., & Byrd, D. L. (2002). The Tower of London spatial problem-solving task: Enhancing clinical and research implementation. *Journal of Clinical and Experimental Neuropsychology*, *24*(5), 586–604.

Carder, H., Handley, S., & Perfect, T. (2004). Deconstructing the Tower of London: Alternative moves and conflict resolution as predictors of task performance. *The Quarterly Journal of Experimental Psychology A*, *57*(8), 1459–1483.

Cools, R. (2006). Dopaminergic modulation of cognitive function-implications for l-DOPA treatment in Parkinson's disease. *Neuroscience and Biobehavioral Reviews*, *30*(1), 1–23.

Culbertson, W. C., Moberg, P. J., Duda, J. E., Stern, M. B., & Weintraub, D. (2004). Assessing the executive function deficits of patients with Parkinson's disease: Utility of the Tower of London-Drexel. *Assessment*, *11*(1), 27–39.

Fahn, S., & Elton, R. L. (1987). *Unified Parkinson's disease rating scale* Florham Park, NJ: Macmillan Health Care Information.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, *12*(3), 189–198.

Hodgson, T. L., Tiesman, B., Owen, A. M., & Kennard, C. (2002). Abnormal gaze strategies during problem solving in Parkinson's disease. *Neuropsychologia*, *40*(4), 411–422.

Hoehn, M. M., & Yahr, M. D. (1967). Parkinsonism: Onset, progression and mortality. *Neurology*, *17*(5), 427–442.

Humes, G. E., Welsh, M. C., Retzlaff, P. C., & Cookson, N. (1997). Towers of Hanoi and London: Reliability and validity of two executive function tasks. *Assessment*, *4*, 249–257.

Jurica, P. J., Leitten, C. L., & Mattis, S. (2001). *DRS-2 Dementia Rating Scale-2. Professional manual*. Lutz, FL: Psychological Assessment Resources, Inc.

Kafer, K. L., & Hunter, M. (1997). On testing the face validity of planning/problem-sloving tasks in a normal population. *Journal of International Neuropsychological Society*, *3*(2), 108–119.

Kaller, C. P., Unterrainer, J. M., Rahm, B., & Halsband, U. (2004). The impact of problem structure on planning: Insights from the Tower of London task. *Cognitive Brain Research*, *20*(3), 462–472.

Klahr, D., & Robinson, M. (1981). Formal assessment of planning and problem solving in preschool children. *Cognitive Psychology*, *13*, 113–148.

Morris, R. G., Downes, J. J., Sahakian, B. J., Evenden, J. L., Heald, A., & Robbins, T. W. (1988). Planning and spatial working memory in Parkinson's disease. *Journal of Neurology, Neurosurgery, and Psychiatry*, *51*(6), 757–766.

Nelson, H. E., & Willison, J. (1991). *National adult reading test* (2nd ed.). Berkshire, England: NFER-Nelson Publishing.

Newman, S. D., & Pittman, G. (2007). The Tower of London: A study of the effect of problem structure on planning. *Journal of Clinical and Experimental Neuropsychology*, *29*(3), 333–342.

Owen, A. M. (2004). Cognitive dysfunction in Parkinson's disease: The role of frontostriatal circuitry. *Neuroscientist*, *10*(6), 525–537.

Owen, A. M., James, M., Leigh, P. N., Summers, B. A., Marsden, C. D., Quinn, N. P., et al. (1992). Fronto-striatal cognitive deficits at different stages of Parkinson's disease. *Brain*, *115*(6), 1727–1751.

Schnirman, G. M., Welsh, M. C., & Retzlaff, P. D. (1998). Development of the Tower of London-Revised. *Assessment*, *5*(4), 355–360.

Shallice, T. (1982). Specific impairments of planning. *Philosophical Transactions of the Royal Society B Biological Sciences*, *298*(1089), 199–209.

Spitz, H. H., Webster, N. A., & Borys, S. V. (1982). Further studies of the Tower of Hanoi problem-solving performance of retarded young adults and nonretarded children. *Developmental Psychology*, *18*(6), 922–930.

Taylor, A. E., & Saint-Cyr, J. A. (1995). The neuropsychology of Parkinson's disease. *Brain and Cognition*, *28*(3), 281–296.

Taylor, A. E., Saint-Cyr, J. A., & Lang, A. E. (1986). Frontal lobe dysfunction in Parkinson's disease. The cortical focus of neostriatal outflow. *Brain*, *109*(5), 845–883.

Unterrainer, J. M., Rahm, B., Halsband, U., & Kaller, C. P. (2005). What is in a name: Comparing the Tower of London with one of its variants. *Cognitive Brain Research*, *23*(4), 418–428.

Ward, G., & Allport, A. (1997). Planning and problem-solving using the five-disc Tower of London Task. *The Quarterly Journal of Experimental Psychology A*, *50*(1), 49–78.

Winer, B. J. (1962). *Statistical principles in experimental design*. New York: MacGraw-Hill.