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Executive function deficits in patients with dementia of the Alzheimer's type

A study with a Tower of London task

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Abstract

A growing number of studies report a deterioration of the executive function (EF) in dementia of the Alzheimer type (DAT). To evaluate EFs in DAT, a new version of the Tower of London (TOL) task, originally developed by Shallice (1982), was adapted. The new version of the test was built up in its easiest possible feature in order to be administrable to early- or middle-stage demented patients. Seventeen DAT patients, and 17 controls matched for age and sex, were administered the TOL. The protocol followed a “hierarchical paradigm,” that is, simpler problems were embedded in more complex, subsequent problems. Results showed that DAT patients were impaired compared to controls. Both control and DAT groups showed a decrease in percentage of success rate in relation to the number of movements required by the task. On the more complex problems, the performance of DAT subjects was proportionally more impaired. Qualitative analysis revealed that rule breaking was a salient performance feature of the DAT group. These findings are consistent with the presence of an EF deficit in DAT.

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1. Introduction

In dementia of the Alzheimer type (DAT), deterioration of cognitive abilities collectively known as executive function (EF) are increasingly reported (Cummings & Benson, 1992; Grady et al., 1988; Jolles & Hijman, 1983; Passini, Rainville, Marchand, & Joannette, 1995; Patterson, Mack, Gelmacher, & Whitehouse, 1996). Many studies are consistent with the possibility that an impairment in EF occurs early in DAT (see Perry & Hodges, 1999). For instance, Janowsky and Thomas-Thrapp (1993) and Strub and Black (1981) suggested that deficiencies in organizational and executive abilities may signal the early stages of DAT. They reported that tasks depending on familiar information and routine operations are most resistant to disruption. Conversely, new and complex tasks deteriorate most evidently. The presence of early EF dysfunction has been reported by Almkvist (1996), Binetti et al. (1996) and Collette, Andres, and Van der Linden (1999). Lafèche and Albert (1995) administered seven tests to assess EF in DAT patients. They observed that DAT differed significantly from controls on four tests. According to these researchers, performance on these tests was impaired because they require concurrent manipulation of information (e.g., set shifting, self-monitoring, or sequencing) and cue-directed attention (e.g., the ability to use cues to direct attention). Bhutani, Montaldi, Brooks, and McCulloch (1992) used four neuropsychological tests (verbal fluency, delayed alternation, subject-ordered pointing, and the Wisconsin Card Sorting Test) to determine frontal lobe involvement in DAT. They showed that DAT subjects were impaired in the first three tasks. Impairments were present at all stages of the disease and were related to disease severity. In a longitudinal study, Sahakian et al. (1990) observed also the presence of executive dysfunction in the early stage of DAT. In a prospective study, Fabrigoule et al. (1998) showed that preclinical cognitive deficits in Alzheimer's disease may be interpreted as the disturbance of controlled processes.

Royal, Mahurin, and Cornell (1994) found that a measure of EF was better correlated than mini mental status examination (MMSE) scores with functional status. According to them, this observation suggests that executive dysfunction has a substantial role in determining patient's level of functioning that is perhaps more important than global cognitive impairment. Executive dysfunctions have been associated with greater neuropsychiatric symptomatology (Chen, Sultzer, Hinkin, Mahler, & Cummings, 1998). Moreover, a number of studies associated impairments in EF with inability to perform daily activities in AD (Chen et al., 1998; Grigsby, Kaye, Baxter, Shetterly, & Hamman, 1998; Willis et al., 1998). For Royal (1994) and Royal et al. (1994), DAT might be better understood as a syndrome of executive dyscontrol. Roman and Royall (1999) have suggested that impairments in EF were a robust determinant of functional status, disability, and dementia.

In sum, the evaluation of EF in DAT is recognized as an important aspect in clinic and may be useful for the early detection of DAT. However, classical EF tasks are not always adapted for DAT population. For instance, Chen et al. (1998) observed that seven of the proposed executive skills tests could not be performed by 32–55% of a moderately impaired DAT group. Therefore, an effort needs to be provided to adapt these tests to that population.

The EF includes a broad range of abilities whose number and nature vary according to different authors. In the literature, a number of interrelated skills have been distinguished, including recognition and selection of appropriate goals, manipulation of concurrent information

(e.g., set shifting, sequencing, and monitoring), cue-directed attention, concept formation (e.g., abstraction) (Anderson, 1980; Denkla, 1996; Glosser & Goodglass, 1990; McCarthy & Warrington, 1990). For Welsh, Pennington, and Groisser (1991), it involves strategic planning, impulse control, and organized search, as well as flexibility of thought and action. Thus, inhibitory mechanisms play a central role in EF (Luria, 1966, 1973; Shallice, 1982). Subjects must maintain a smooth flow of planning and control behavior in the face of potential distractions. At each step of the task, they have to obtain relevant information in light of their goal (or subgoals), on one hand, and they have to inhibit irrelevant information, on the other hand. Moreover, the immediate attainment of one subgoal may conflict with the attainment of more appropriate subgoals that lead to the final goal.

Within this broadly conceived framework, our study will focus on a central feature of the EF: planning abilities which imply the attainment of a goal through a series of intermediate steps which do not necessarily lead directly to that goal. In order to study this type of processes in EF, Shallice (1982) elaborated the Tower of London (TOL) test. This test was designed as a means of identifying impairments of such supervening planning processes. It was derived from the Tower of Hanoi Disk-Transfer task, which consists of well-defined start and goal states, as well as a constrained set of legal operators (i.e., behavioral responses) for movements through the problem solving space. The TOL requires planning such as means—ends analysis in order to solve a series of successively more difficult problems and to avoid incorrect moves. Solving TOL problems requires the rearrangement of colored balls on three pegs to match a goal arrangement (i.e., duplication of the experimenter's ball configuration) of balls presented on an adjacent model (start position). The simpler problems can be solved by directly transferring balls from a start to a goal position, whereas complex problems involve planning the correct sequence of moves. In these cases, the goal is achieved by being broken down into subgoals. The TOL is a non-verbal task. It is also a novel task for all people, so that subjects did not have the opportunity to previously develop subroutines. This test is well recognized to measure EF (Anderson, Anderson, & Lajoie, 1996). It has been administered to many populations, including traumatic head injury cases (Azouvi et al., 1995; LeThiec et al., 1999; Levin et al., 1996), and patients with focal frontal lesions (Glosser & Goodglass, 1990; Goel & Grafman, 1995; Shallice, 1982; Shallice & Burgess, 1991).

Thus, it follows that the TOL test appears to be appropriate for the assessment of EF, which is an important clinical aspect in DAT. However, concerning this population, it may be necessary to use a simplified version of the task. For the elderly population, Allamano, Della Sala, Laicon, Pasetti, and Spinnler (1987) developed a version of the TOL which was given to 131 normal subjects. They found a decline of performance in normals. There was no significant influence of education and sex on the test performance. There is, however, a number of difficulties with their testing procedure. First, there was a time limit in the execution of the problems and this is a potential problem for a population who could have a sensorimotor slowness. Second, in presence of rule breaking, the examiner stopped the test to remind the subject that a rule has been broken and the scoring system is complex and used global score. However, the “microanalysis” of individual performances (e.g., types of error) often provides a good clinical insight on patient's cognitive disturbances.

The goal of this research was to study EF deficits in DAT by means of a new, adapted version of the Shallice (1982) TOL test. This version follows a “hierarchical paradigm,” that is, simpler

problems are embedded in more complex, subsequent problems. Moreover, it should allow assessment of these types of deficits in DAT patients, and control the basic abilities involved in this task, with the subject beginning with very simple problems and then going through more and more complex problems (the complexity is defined by the minimum number of moves needed to match the model). This task also allows a qualitative analysis of patient's errors, providing further knowledge of the underlying deficits.

2. Method

2.1. Subjects

The experimental group was composed of 17 DAT patients (10 women, 7 men) whose mean age was 72.0 (S.D. = 5.1). Ages of patients ranged from 62 to 79. All DAT patients were given a diagnosis of DAT by a senior staff neurologist according to the criteria developed by NINCDS-ADRDA group (McKahn et al., 1984). Laboratory testing was performed to rule out some other possible causes of dementia. Patients with a history of severe head injury (loss of consciousness for more than 48 h), alcoholism, and depressive symptomatology were excluded. To reduce the possibility of including multi-infarct dementias, patients with a score of 5 or greater on the Hachinski scale were excluded. The dementia severity measured by the MMSE (Folstein, Folstein, & McHugh, 1975) was mild to moderate (mean MMSE score = 21.5; S.D. = 2.4).

The normal control group was composed of 17 healthy seniors with a mean age of 72.9 (S.D. = 4.7). Ages of subjects ranged from 63 to 79. The mean MMSE was 27.6 (S.D. = 1.7). They were matched with the experimental group for age and sex. There was no significant difference in the number of years of schooling between the groups. Control subjects were randomly selected from a list of beneficiaries of a pension fund. None of them showed any sign of dementia according to the DSM-III-R criteria (Diagnostic and Statistical Manual of Mental Disorders, 1987). Exclusion criteria included cerebrovascular disease, Parkinson's disease, severe trauma (loss of consciousness for more than 48 h), depressive symptomatology, or chronic alcoholism.

2.2. Material and procedure

The TOL materials included two kits, one for goal arrangement (examiner's kit) and one for start position (subject's kit) (Fig. 1), each made of a wooden base 22 cm × 6 cm × 2 cm. Three wooden pegs of different lengths (12, 8, and 4.5 cm) were mounted on the base. For each kit, there were three colored balls (yellow, red, and blue), 3 cm in diameter, with holes cut through the core so that they can easily be placed on the pegs.

The protocol included 15 problems organized in the following way. First, three problems of five movements were selected. Two of them were selected according to the presence or absence of a "trigger." A trigger is an incitation to the subject, at the beginning of the task, to move a ball to its final position according to the model (Collette & Van der Linden, 1993). For instance, Problem 13 (Fig. 1) contains a "positive trigger," which helps to reproduce the model. Problem

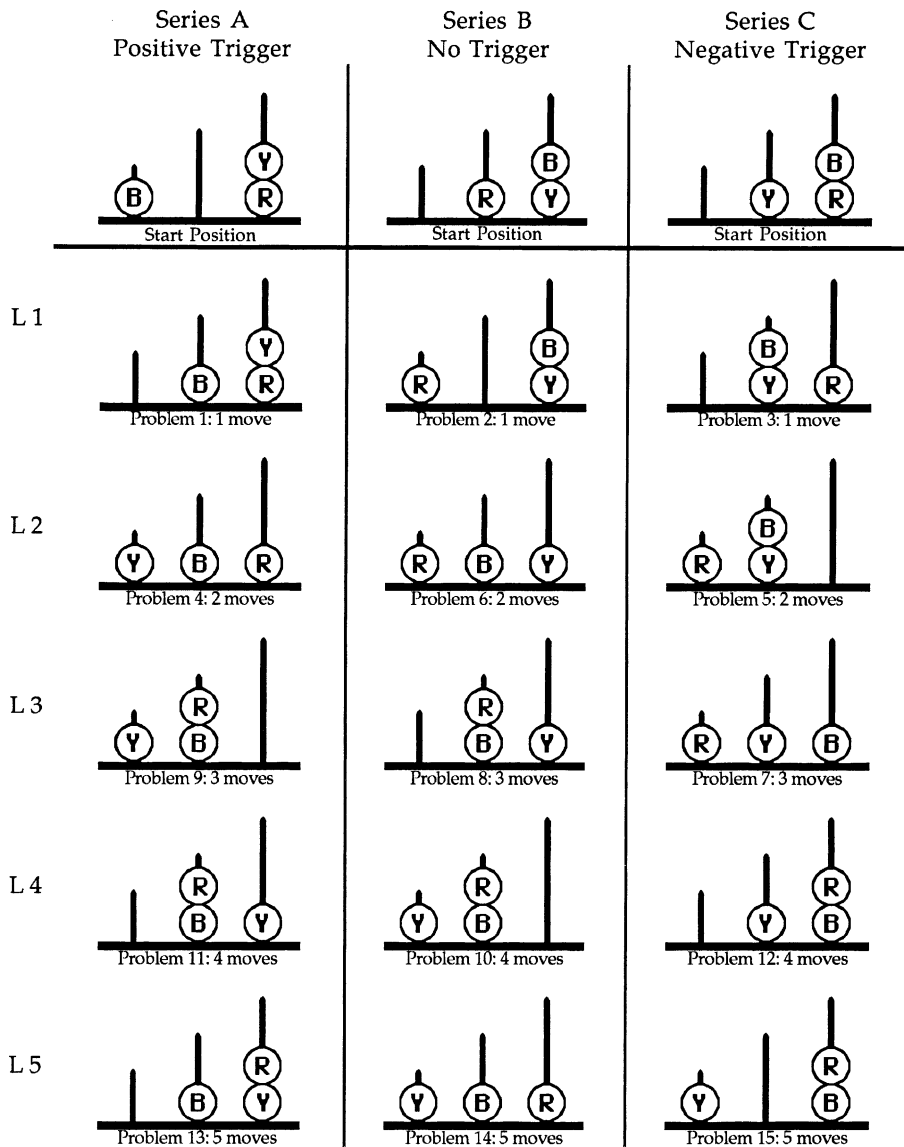


Fig. 1. Schematic representation of the adaptation of the Tower of London stimuli. R, Y, and B designate positions for the red, yellow, and blue balls on the pegs. There is one start position for each series. Three problems were given at each level (L) of complexity.

15 contains a “negative trigger,” which is an obstruction to the following moves. Hence, it is a potential distracter that could lead to a failure in appropriate goal-directed behavior. Problem 14 is “neutral,” that is, it contains no trigger.

Each of the three original problems was segmented into five steps (Fig. 1). Each step was used to define a different problem. Hence, each of the three original problems made up a series

of five problems of different levels of complexity, defined by the minimum number of moves needed to match the model. Therefore, the protocol was made up of three series and each of them included five problems requiring from one to five movements. Moreover, the protocol followed a hierarchical design, that is, simpler problems were embedded in more complex, subsequent problems (Fig. 1). Operationally, in each series, this means that a problem of Level L includes all aspects of L-1 problem, and “something more.”

Each subject was tested individually in a quiet office. Using two pretest problems (of two movements each), the examiner explained to the subject that he had to fit the balls onto the pegs of his kit in the same way as the examiner’s goal model. The examiner explained that he had to comply with the following general rules: (a) reproduce the examiner’s model in a minimum number of moves; (b) move only one ball at a time; (c) place not more than one ball on the shortest peg, and not more than two balls on the middle one; (d) always move a ball on one or another peg (i.e., not lay down on the table or on the base). The instructions emphasized accuracy rather than speed of performance.

Different peg/ball combinations were presented on the model, each constituting a problem. For each problem, the preparation of the configuration on the subject and examiner’s kits was hidden. In order to make sure that patients understood rules, and because DAT patients tend to perform at floor on traditional “frontal tests” (Bhutani et al., 1992), problems were presented in order of increasing difficulty, from one to five movements (Fig. 1). There was no time limit. The subject was asked to say when he had finished. In the case of violation of rules, they were reminded at the end of the problem. When wrong configurations were observed, at the end of the total series of 15 problems, the examiner explored a potential visuospatial impairment with the following procedure. For each problem, the examiner reintroduced the model that had been failed. The subject was given a kit with the ball lying on the table. He was invited to reproduce the model without any limiting rules. In order to test the validity of the TOL in evaluating EF, subjects were also evaluated with two other tests, that is, the Isaacs Set Test of Verbal Fluency (Isaac & Kennie, 1973) and the Stroop Test (Stroop, 1935). For instance, the Stroop Test has appeared to be sensitive to the presence of a DAT (Fisher, Freeds, & Corkin, 1990; Spieler, Balota, & Faust, 1996).

2.3. Statistical analyses

As the data were not normally distributed, the statistical analyses were made by the means of non-parametric tests (Mann–Whitney *U*-test, Wilcoxon test, and signed rank tests). Thus, the statistical tests were made on the ranked scores of subjects. However, the mean scores were also reported as a general indicator of data central tendency. The sequentially rejective Bonferroni test was chosen to take into account the multiple significance tests and the correlation between the tests (Simes, 1986).

In addition, to test the presence of a hierarchy in performance, a Guttman’s scalogram analysis was conducted for each series. The Guttman’s scalogram approach is used to order a group of items or tasks into a linear hierarchy and to evaluate whether or not the hierarchy is unidimensional and cumulatively hierarchical. The degree to which a group of items or tasks is judged to be unidimensional and cumulative is determined by the extent to which a “success” (scores of 1) on any item or task co-occur with success on all items or tasks ranked

as less difficult (here in terms of number of movements). The inverse is also true. That is, a hierarchy is unidimensional and cumulative insofar as “failures” (scores of 0) on an item or task co-occur with failures on items ranked as “more difficult” (see Green, 1956; Guttman, 1944). On a Guttman scale, each profile of performance is greater than that preceding it on the scale, so that it records all the traits of the preceding one plus some more (Stouffer et al., 1950). In practice, “perfect scales” are rare, but approximate scales can be found. The degree of fit of a Guttman scale can be assessed by a coefficient of scalability. There are different methods to evaluate the presence of a “good scale.” The method of Goodenough’s (1944) has been used here.

3. Results

To investigate global planning efficiency, the total number of successes was first analyzed. One point was given for each problem succeeded (success: score of 1; failure: score of 0). Each group’s performance is summarized in Table 1. Mann–Whitney *U*-test revealed a significant difference between DAT and control groups. Considering the number of problems succeeded at each level, for control subjects, we observed that the means of Levels 1 and 2 were high and decreased slowly from Level 3 to 5. For DAT subjects, the level of performance decreased sharply from Level 2 to 5. For all the levels, except for Level 1, a significant difference was found between the two groups.

Because problems had different levels of complexity (in terms of number of movements), it is likely that some subjects had the same number of success but presented different profiles. That is, considering two subjects with the same score, one could have succeeded at a complex problem while failing at a less complex one. This could mask a higher capacity in problem solving. For this reason, a composed score was used: one point was given for each single movement problem, two points for each two movements problem and so forth for a maximum of 45 points for the complete task. Thus, according to this procedure, the subjects received the corresponding number of points for each problem succeeded. Then, the composed score was calculated by the addition of these points. Results showed that controls performed significantly

Table 1
Performance analysis for control and DAT subjects

	Control <i>M</i> (S.D.)	DAT <i>M</i> (S.D.)	<i>P</i> -value ^a
Raw score	10.7 (1.7)	6.6 (2.3)	.0001
Level 1	2.9 (0.2)	2.9 (0.3)	.6
Level 2	2.9 (0.3)	1.9 (1.0)	.0005
Level 3	1.9 (0.9)	0.9 (0.7)	.009
Level 4	1.7 (0.8)	0.7 (1.0)	.003
Level 5	1.3 (0.7)	0.2 (0.4)	.0001
Composed score	27.6 (6.2)	13.4 (7.8)	.0001

^a Mann–Whitney *U*-test; raw score, maximum = 15; level, maximum = 3; composed score, maximum = 45.

Table 2
Performance analysis (composed score) for each of the three series A–C, for control and DAT subjects

Series	Control <i>M</i> (S.D.)	DAT <i>M</i> (S.D.)
A	11.1 (4.1)	6.2 (3.9)
B	6.7 (4.5)	3.9 (3.3)
C	9.9 (3.6)	3.1 (2.4)

better than DAT (Table 1). Table 2 shows the composed score for each of the three series for both groups.

This composed score was significantly correlated with the performances of the subjects on two standard tests of EF, which are the test of verbal semantic fluency of Isaacs and the Stroop Test ($r = .8$, $P < .0001$; $r = .5$, $P < .01$, respectively).

Considering the 15 problems individually, Figure 2 shows the percentage of success for both groups. A visual examination of Figure 2 shows, for both groups, a global decrease in the percentage of success in relation to the number of movements; as the problems became harder (in terms of number of movements), the number of problems solved decreased. But this decrease was not strictly linear, that is, some problems had a higher percentage of success than others that were considered to be easier. For example, for the control group, Problem 12 (four movements) had a higher percentage of success than Problem 7 (three movements).

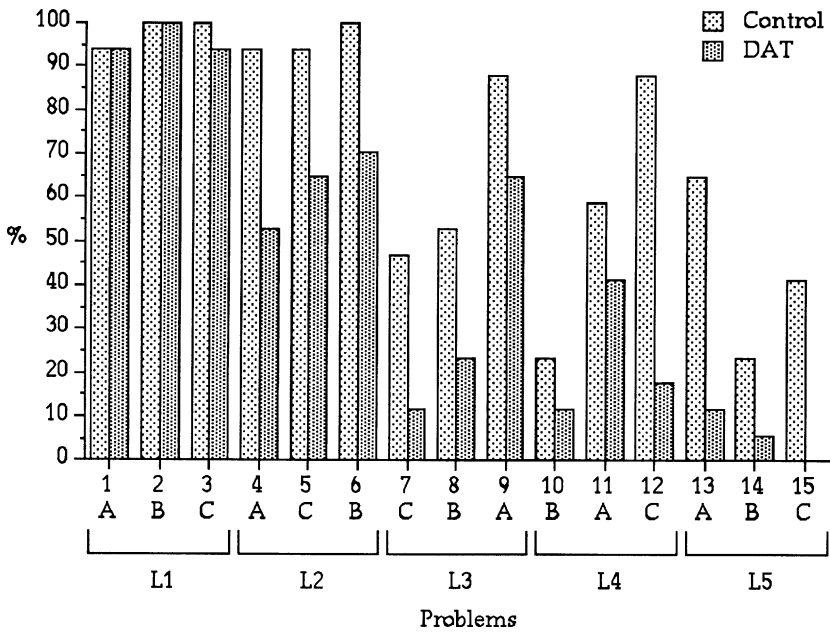


Fig. 2. Percentage of success for each problem for control and DAT subjects. Letters A, B, and C represent the series, and letter L represents the levels (note that all DAT patients failed Problem 15).

Table 3

Coefficients of scalability for each series for control and DAT groups

Series	Control	DAT
A	0.30	0.32
B	0.91	0.86
C	0.05	0.46

Coefficient of scalability must be >0.60 (method of [Goodenough, 1944](#)).

In the DAT group, subjects performed better on Problem 11 (four movements) than on Problem 8 (three movements).

As described above, simpler problems were embedded in more complex, subsequent problems. In other words, the protocol followed a hierarchical design. To test the presence of a hierarchy in performance, a Guttman's scalogram analysis was conducted for each series. [Table 3](#) shows the coefficients of scalability for control and DAT groups. For both groups, performance in Series B respected a hierarchy, that is, when subjects were successful on a problem of Level L, they regularly were successful on a problem of Level L-1. However, for both groups, this regularity was not observed in Series A and C (i.e., low coefficient of scalability). When a subject was successful on a problem of a certain level, he was not necessarily successful on other problems at the same level of difficulty, which was particularly noticeable for Levels 3 and 4.

Comparison of adjacent levels of performance for the DAT group showed a statistical difference between Levels 1 and 2 (signed rank test = -42.5 , $P < .005$) and between Levels 2 and 3 (signed rank test = -34.5 , $P < .004$). There was no significant difference between other adjacent levels. For the control group, there was a statistical difference between Levels 2 and 3 (signed rank test = -41.5 , $P < .002$). We observed no significant difference between other adjacent levels.

The triggering effect was analyzed for Problems 13 and 15. This effect can be observed on the first move. For Problem 13, if subjects were influenced by the positive trigger, they moved the blue ball to the middle peg ([Fig. 1](#)). This move was completed by 13 control subjects and 11 DAT subjects. There was no statistical difference between the groups. Note that this first move was a necessary but insufficient condition for a success. For Problem 15, if subjects were influenced by the negative trigger, they moved the yellow ball to the shortest peg in its final position ([Fig. 1](#)). However, this move was a mistake because it constituted an obstruction to the following moves. Hence, subjects had to inhibit this action. This move was performed by 8 control subjects and 15 DAT subjects. This difference was statistically significant ($\chi^2 = 6.6$, $P < .01$).

3.1. Error type analysis

For the qualitative analysis of performance, three types of errors were distinguished in reference to the rules given to the subject: (1) "wrong final configuration" reflects, as it is suggested, the accuracy of the final configuration after subjects had finished their moves; (2) "rule breaking" relates to rules b, c, and d of the general rules presented above (e.g., picking

Table 4
Number of error types for control and DAT subjects

	Control Number (%)	DAT Number (%)
Wrong final configuration	2 (2.7)	6 (4.2)
Rule breaking	42 (57.5)	120 (84.5)
Excess movements	29 (39.8)	16 (11.3)
Total of errors	73 (100)	142 (100)

up more than one ball at a time); (3) “excess movements” concerns the reproduction of the model with more moves than the minimum number required.

Table 4 summarizes each group’s error types. First, considering the accuracy of the final production, very few errors were observed in both groups. From a total of 255 configurations possible (17 subjects × 15 problems), DAT patients failed on only six final configurations, and control subjects failed on only two configurations. In all cases, the subjects succeeded when they were invited to reproduce the model without any limiting rules.

Table 4 shows that “excess movements” errors counted for 39.8% of the total number of errors observed in the control group, whereas it represented 11.3% of failures on problems for the DAT group. Proportionately, control subjects made more “excess movements” errors than DAT subjects. In the same vein, Table 4 also illustrates that for the 15 problems, the most frequent cause of failure for both groups is the “rule-breaking” type. This proportion was particularly high for the DAT group (84.5%). In other words, in the large majority of the cases, in this group, problems were failed due to one rule-breaking incident.

Table 5 presents, for both groups, performance means and standard deviations of problems having at least one rule-breaking incident at the different levels. Intergroup comparisons showed that in all levels, except for Level 1, DAT subjects committed significantly more rule-breaking errors than control subjects. Moreover, within-group comparisons showed that, globally, as the complexity of problems increased, the number of rule-breaking incidents increased. For DAT subjects, rule-breaking incidents were very rare in Level 1, really emerged at Level 2, and increased until Level 5. An additional analysis of rule-breaking incidents in

Table 5
Means of problems at each level presenting at least one rule-breaking incident in control and DAT subjects (maximum of three by problems level)

Levels	Control <i>M</i> (S.D.)	DAT <i>M</i> (S.D.)	<i>P</i> -value ^a
1	–	0.1 (0.2)	.3
2	0.1 (0.2)	0.9 (1.0)	.001
3	0.8 (1.0)	1.8 (1.0)	.003
4	0.8 (1.0)	1.9 (1.2)	.002
5	0.8 (1.0)	2.5 (0.9)	.003

^a Mann–Whitney *U*-test.

Level 5 problems showed that 84% of these incidents occurred in the first two movements. For control subjects, no rule-breaking incident was observed in Level 1, very few in Level 2; they emerged in Level 3 and remained constant until Level 5.

4. Discussion

In the present study, a modified version of the TOL test, originally designed by Shallice (1982), has been proposed to investigate EF of DAT patients. DAT patients show a deficit in the EF as measured by this task. Although considerably simplified, this adapted version of the TOL is a good tool to measure EF since the scores are strongly correlated to subject's performances on tests known to be standards of EF, such as the Stroop Test or the Isaacs Set Test. This disability was observed in quantitative and qualitative analyses of performances.

Quantitative analysis showed a global diminution in performance as the complexity of the problem increased; the percentage of success in relation to the number of movements required by the task decreased for control and DAT groups. However, on problems requiring higher-level planning ability (i.e., more moves), DAT subjects were significantly more impaired than the control subjects. Our data suggest that the breakdown in EF in DAT appears "earlier" in problem complexity, and the decrease is more abrupt. The problems, even in their easiest formulations, demand the ability to plan, an ability which is obviously impaired. These findings are consistent with previous literature, which has reported an executive deficit in DAT (Janowsky & Thomas-Thrapp, 1993; Lafière & Albert, 1995; Royal, 1994).

In addition to an accurate quantification of planning efficiency, qualitative analysis of performances provided important information regarding EF. For complex problems, the TOL task requires planning, that is, a non-routine generation and execution of a sequence of spatial moves to solve the problem satisfactorily. Obviously, planning in TOL includes the coordination of several distinct, though interactive, cognitive components of EFs. It necessitates a series of different operations which include the following: (a) a visuospatial analysis of peg/ball combinations on two kits; (b) a mental manipulation of visuospatial images of the balls in order to produce possible solutions (i.e., anticipation); (c) the matching of the final position of the image sequences to the goal arrangement specified; (d) the sufficiently long on-line maintenance (i.e., in working memory (WM)) of the mental representation of the successful sequence of moves that enables its execution, but also the memorization of the move sequences that have been considered but rejected as possible solutions; (e) the correct execution of a sequence of moves with respect to the rules (self-monitoring); and finally (f) the evaluation of the combinations performed with the goal states, and if incorrect, the correction of mistakes (i.e., engaging a new plan). However, the nature and the degree of intervention of these operations, generally associated with EFs (Luria, 1966, 1973) are not well known. To clarify the underlying nature of the patient's EF deficits, it is important to take into account these operations when explaining the performance.

Before the subject begins to manipulate balls, the initial and goal states must be processed with attention directed to the color and spatial configuration of the balls. The "visuospatial" capacity is a cognitive process to consider. In TOL tasks, it concerns the comprehension and the coordination within a global reference system of the right–left and up–down relations between

the balls. In this study, the low rate of wrong final configurations suggests no deficit in these capacities, for both groups. Moreover, in the few cases of problems failed, all the subjects could reproduce the goal arrangement at the end of the task. In sum, the deficits observed in DAT cannot be explained by a visuospatial deficit.

As we have seen earlier, for both groups, the number of problems solved decreased as the planning difficulties (i.e., in more complex problems) increase. This might be interpreted in terms of a general overload of the cognitive capacities, but which have different impacts according to the group of subjects. DAT patients tend to break the rules to achieve a given combination, or a goal state, more often than control subjects. The number of rule breaking increases as planning difficulties increase. In fact, frequent rule breaking is a salient performance feature of the DAT group. This characteristic was also reported by Laflèche and Albert (1995). Self-monitoring is an important component of EF (Borkowski & Burke, 1996; Luria, 1973; Luria & Homskaya, 1964). The TOL task includes the ability to self-monitor his/her own actions according to the rules for the attainment of the goal. Rule breaking may be interpreted as the result of the deterioration by the disease of a specific modulating mechanism (Milner, 1982; Petrides, 1985), which regulates the subject's responses in reaction to changes in the environment following his/her action or inaction. In the TOL task, different information must be treated in parallel. As the complexity of the problems increases, it is necessary to plan and to select the appropriate sequence in which subgoals can be reached. However, the moves must be carried out in accordance with specific rules that must be kept in mind. Since the self-monitoring process is severely deteriorated in DAT, it results in a general loss of control over the action. The underlying deficit may be attentional, specifically, in disengaging attention from the current focus.

Considering subjects of the control group, when confronted with difficulties they make proportionately more “excess movement” errors than DAT subjects. On one hand, this suggests that control subjects can regulate better their actions according to the rules. They still have a better self-monitoring capacity than DAT subjects. On the other hand, considering the percentage of rule breaking (Table 4), obviously this ability is weakened, which results in a temporary and occasional disregard for instructions. In other words, in a number of control subjects, although they can regulate their actions according to the rules, it is not a sufficient condition and planning difficulties on complex problems must be overcome.

Memory capacity is a central issue in the interpretation of performances. Because memory deficit is a major clinical sign in DAT, it is crucial to determine its impact on TOL performances. However, different aspects of memory dysfunction contributions must be distinguished. The first is related to the high number of rule-breaking incidents in the DAT group. One explanation could be that the DAT subjects have a low level of performance because they forget the rules. However, this test minimizes memory demands since the stimuli remain in front of the subject at all times. Moreover, rules were reminded at the end of the problem in the case of violation. The fact that the number of rule-breaking incidents increases, as problems become more complex is consistent with an incapacity to plan. This interpretation is reinforced by the finding that most rule-breaking incidents on the more complex problems occurred in the first two movements. This suggests that rule breaking is not dependent of time but rather, is a reaction to the initial difficulty of the problems. Unable to anticipate the sequence of moves, subjects bypass difficulties by breaking one of the rules. In other words, disabilities in self-monitoring

lead to the disintegration of complex programs of activity and reset their replacement by either simpler or more basic forms of behavior. This kind of dysfunction is characteristic of a planning incapacity (Luria, 1966, 1969, 1973; Milner, 1964; Stuss & Benson, 1986).

The second aspect concerns WM, which is a coherent set of specialized short-term memory functions (Baddeley, 1986). It implies that certain information remains at the forefront of cognition and guides appropriate responses, even when this information is no longer present. Information can remain temporarily “on-line” and in position to guide behavior. WM is a means by which some information is sustained or symbolically fixed in mind while parallel processing is operated. For Pennington, Bennetto, McAleer, and Roberts (1996), WM is central for maintaining the various constraints or situational variables relevant to the current context. The major role of WM processes in the EF have been emphasized by different authors (Barkley, 1996; Denkla, 1996; Eslinger, 1996; Welsh et al., 1991).

In the TOL task, problems of different levels of complexity (in terms of number of movements) differ in the potential WM demands (Anderson, 1980; Owen, Downes, Sahakian, Polkey, & Robbins, 1990). In less complex problems, the representation of the sequence previously elaborated must be maintained over a shorter time interval. In more complex problems, subgoals must be defined and sequences of moves directed toward its attainment have to be selected. Once the solution has been found, it must be held in short-term memory and transposed into the appropriate sequence of motor movements before it can actually be executed. The intermediate problem stages generated must be represented in WM. Even the move sequences for a particular problem that have been considered but rejected as possible solutions must be memorized. Hence, the more complex the problems are, the greater the memory storage load. Consequently, if memory load is the key factor, a global reduction of percentage of success should be observed as the complexity of problems increases.

Since WM is affected in DAT (Baddeley et al., 1991; Van der Linden, 1994), one could suggest that subjects can correctly plan, evaluate the problem, and then generate, refine, and revise a solution, but fail to represent sequences of moves in WM and/or to recuperate them. DAT performances may be impaired in retaining a sequence of spatial moves in short-term memory for the length of time required to allow its successful execution to take place. This research did not directly address this question, but the data suggest a possible impact of a WM deficit. Figure 2 illustrates a global decrease in performance, which is, at first sight, concordant with a memory deficit. However, as we have seen, the percentage of success is not linear. For both groups, some problems have a lower percentage of success than those that are more complex. This has been confirmed by the low coefficient of scalability in Series A and C (remember that inside each series simpler problems were embedded in more complex ones). Moreover, if memory load is again the central factor, problems at the same level (within-level analysis) should have more or less the same percentage of success since memory storage load is presumed to be the same. But, as we have seen, it is not the case for Levels 3, 4, and 5, for both groups. Percentage of success varies considerably between problems within these levels. This also illustrates that the complexity of problems, in terms of number of movements, clearly is not the only factor to intervene. The complexity of the problems does not directly correspond to the level of difficulty for subjects.

In the TOL task, differences, at times large, in the rate of success for problems requiring the same number of moves to be solved have been observed in other research. For instance,

Anderson et al. (1996) administered the version of Shallice (1982) to a large sample of children to provide normative data. They observed that success does not correspond directly to item difficulty. Moreover, for some problems in which there is an equal number of moves required for a solution, the rate of success varies considerably. However, the reasons for these discrepancies were not discussed. In summary, in the TOL task, WM is an important factor in performance. But, obviously others factors intervene.

As suggested earlier, the efficiency scores in TOL tasks also reflects the ability to resist distractors (e.g., negative trigger) and inhibit maladaptive responding. Impairments in inhibition in DAT were reported in different studies (Amieva et al., 1998; Faust, Balota, Duchek, Gernsbacher, & Smith, 1997; Spieler et al., 1996). As illustrated in Problem 15 (which has a negative trigger), potential distractors could lead to a failure of appropriate goal-directed behavior. In this case, subjects must be able to inhibit, in the first move, an incorrect but prepotent response. There is a dynamic interaction between the strength of the actual influential response and the alternative response retained in WM (Pennington, 1994). Note that the converse is also true. A salient alternative response could have a benefit effect, as we have seen in Problem 13 in the first move. However, in this case, it was not sufficient, as suggested by the low rate of success in DAT. Moreover, as suggested above, one may also hypothesize that an inhibition dysfunction is at the origin of rules breaking. In this line, subjects have difficulty resisting the impulse to act upon stimuli and to interpose a goal-directed action while adhering to the rules. The goal-state seems to dominate at the expense of rules and leads DAT subjects to employ more routine procedures. For example, in Problem 12, the subjects had to proceed to the inversion of the colored balls (Fig. 1). Being unable to plan the correct sequence of (four) moves, the DAT patients do the rotation of the colored balls by using both hands. In others words, it seems that the subjects were centered on the inversion and ignored the rules. This is likely a version of the “stimulus-bound effect” reported in DAT (Passini et al., 1995; Rainville, 1992). Interestingly, when the rules were remembered, often the DAT patients protested having violated them.

In sum, inhibitory mechanisms play a central role in TOL tasks (Levin et al., 1996; Pennington, 1994). As suggested by the findings of other studies, and the performance in the Stroop Test, the DAT patients have a dysfunction in inhibitory processes, which obviously have a repercussion at different levels of the hierarchy of decisions in the TOL task. Easy TOL problems may be solved automatically by the selection of the appropriate moves following inspection of the array, and require minimal planning. For more difficult problems, in addition to the generation of multiple, sequential moves, subjects are confronted with several, more or less salient erroneous response alternatives. While keeping in mind (in WM) the rules, not only does a good sequence of moves have to be generated, but, corollary, distracting response alternatives must be controlled.

In conclusion, the findings of this study support the clinical observations of an EF impairment in DAT. The adapted version of the TOL task used in the current study gives a valid and reliable assessment of EF in DAT. This quick and easily administered version proves to be a useful clinical tool. The subject begins with very simple problems and then goes through more and more complex problems. In this version, basic abilities involved, such as the comprehension of rules and visuospatial abilities, are controlled. Both quantitative and qualitative analysis distinguish DAT patients and normal participants. While a number of traditional executive measures employ a global score as indicators of performance, the qualitative aspects

of performance in the current procedure give a more accurate picture of EF. For instance, we observed that DAT subjects, when confronted with difficulties, make proportionately more rule-breaking errors than control subjects suggesting an impairment in self-monitoring capacity, whereas control subjects make more “excess movements.” To explain the deficits in DAT in the TOL task, WM impairments and/or dysfunction in inhibitory processes are good candidates.

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References

- Allamano, N., Della Sala, S., Laicon, M., Pasetti, C., & Spinnler, H. (1987). Problem solving ability in aging and dementia: Normative data on a non-verbal test. *Italian Journal of Neurological Sciences*, 8, 111–120.
- Almkvist, O. (1996). Neuropsychological features of early Alzheimer's disease: Preclinical and clinical stages. *Acta Neurologica Scandinavica*, 165, 63–71.
- Amieva, H., Lafont, S., Auriacombe, S., Rainville, C., Orgogozo, J.-M., Dartigues, J.-F., & Fabrigoule, C. (1998). Analysis of error types in the Trail Making Test evidences: An inhibitory deficit in dementia of the Alzheimer type. *Journal of Clinical and Experimental Neuropsychology*, 20, 280–285.
- Anderson, J. R. (1980). *Cognitive psychology and its application*. New York: Freeman.
- Anderson, P., Anderson, V., & Lajoie, G. (1996). The Tower of London test: Validation and standardization for pediatric populations. *Clinical Neuropsychologist*, 10, 54–65.
- Azouvi, P., Marlier, N., Van der Linden, M., Coyette, F., Tognet, G., De Clarens, S., & Bussel, B. (1995). Etude des troubles de la stratégie de patients traumatisés crâniens graves à l'aide du test de la Tour de Londres. In L. Simon, J. Pélissier, & C. Hérisson (Eds.), *Actualités en rééducation fonctionnelle et réadaptation* (pp. 11–15). Paris: Masson.
- Baddeley, A. D. (1986). *Working memory*. Oxford: Oxford University Press.
- Baddeley, A. D., Bressi, S., Della Sala, S., Logie, R., & Spinnier, H. (1991). The decline of working memory in Alzheimer's disease. *Brain*, 114, 2521–2542.
- Barkley, R. A. (1996). Linkages between attention and executive functions. In G. R. Lyon & N. A. Krasnegor (Eds.), *Memory, attention, and executive function* (pp. 307–325). Baltimore: Brookes Publishing.
- Bhutani, G. E., Montaldi, D., Brooks, D. N., & McCulloch, J. (1992). A neuropsychological investigation into frontal lobe involvement in dementia of the Alzheimer type. *Neuropsychology*, 6, 211–224.
- Binetti, G., Magni, E., Padovani, S., Cappa, S. F., Bianchetti, A., & Trabucchi, M. (1996). Executive dysfunction in early Alzheimer's disease. *Neurosurgery and Psychiatry*, 60, 91–93.
- Borkowski, J. G., & Burke, J. E. (1996). Theories, models and measurements of executive functioning: An information processing perspective. In G. R. Lyon & N. A. Krasnegor (Eds.), *Attention, memory, and executive function* (pp. 235–261). Baltimore: Brookes Publishing.
- Chen, S. T., Sultzer, D. L., Hinkin, C. H., Mahier, M. E., & Cummings, J. L. (1998). Executive dysfunction in Alzheimer's disease: Association with neuropsychiatric symptoms and functional impairment. *Journal of Neuropsychiatry and Clinical Neurosciences*, 10, 426–432.

- Collette, F., Andres, P., & Van der Linden, M. (1999). Lobes frontaux et mémoire de travail. In M. Van der Linden, X. Seron, D. Le Gall, & P. Andres (Eds.), *Neuropsychologie des lobes frontaux* (pp. 89–114). Marseille: Solal.
- Collette, F., & Van der Linden, M. (1993). *Une adaptation du test de la Tour de Londres*. Bruxelles: Service de Neuropsychologie, Université de Liège.
- Cummings, J. L., & Benson, D. F. (1992). *Dementia: A clinical approach*. Boston: Butterworth-Heinemann.
- Denkla, M. B. (1996). A theory and model of executive function: A neuropsychological perspective. In G. R. Krasnegor & N. A. Krasnegor (Eds.), *Attention, memory, and executive function* (pp. 263–278). Baltimore: Brookes Publishing.
- Diagnostic and Statistical Manual of Mental Disorders (DSM-III-R). (1987). (3rd ed. revised). Washington, DC: American Psychiatric Association.
- Eslinger, P. J. (1996). Conceptualizing, describing and measuring components of executive function. In G. R. Lyon & N. A. Krasnegor (Eds.), *Attention, memory, and executive function* (pp. 367–395). Baltimore: Brookes Publishing.
- Fabrigoule, C., Rouch, I., Taberly, A., Letenneur, L., Commenges, D., Mazaux, J.-M., Orgogozo, J.-M., & Dartigues, J.-F. (1998). Cognitive process in preclinical phase of dementia. *Brain*, 121, 135–141.
- Faust, M. E., Balota, D. A., Duchek, J. M., Gerasbacher, M. A., & Smith, S. (1997). Inhibitory control during sentence comprehension in individuals with dementia of the Alzheimer type. *Brain and Language*, 57, 225–253.
- Fisher, L. M., Freed, D. M., & Corkin, S. (1990). Stroop color-word test performance in patients with Alzheimer's disease. *Journal of Clinical and Experimental Neuropsychology*, 12, 745–758.
- Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). Mini-mental state. *Journal of Psychiatric Research*, 12, 189–198.
- Glosser, G., & Goodglass, H. (1990). Disorders in executive control functions among aphasic and other brain-damaged patients. *Journal of Clinical and Experimental Neuropsychology*, 12, 485–501.
- Goel, V., & Grafman, J. (1995). Are the frontal lobes implicated in planning functions? Interpreting data from the Tower of Hanoi. *Neuropsychologia*, 5, 623–642.
- Goodenough, W. H. (1944). A technique for scale analysis. *Educational and Psychological Measurement*, 4, 179–190.
- Grady, C. L., Haxby, J. V., Horwitz, B., Sundaram, M., Berg, G., Schapiro, M., Friedland, R. P., & Rapaport, S. L. (1988). Longitudinal study of the early neuropsychological and cerebral metabolic changes in dementia of the Alzheimer type. *Journal of Clinical and Experimental Neuropsychology*, 10, 576–596.
- Green, B. F. (1956). A method of scalogram analysis using summary statistics. *Psychometrika*, 21, 79–88.
- Grigsby, J., Kaye, K., Baxter, J., Shetterly, S. M., & Hamman, R. F. (1998). Executive cognitive abilities and functional status among community-dwelling older persons in the San Luis Valley health and aging study. *Journal of American Geriatric Society*, 46, 591–596.
- Guttman, L. (1944). A base for scaling qualitative data. *American Sociological Review*, 9, 139–150.
- Isaac, B., & Kennie, A. (1973). The set test as an aid to the detection of dementia in old people. *British Journal of Psychiatry*, 123, 467–470.
- Janowsky, J. S., & Thomas-Thrapp, L. S. (1993). Complex figure recall in the elderly: A deficit in memory or constructional strategy. *Journal of Clinical and Experimental Neuropsychology*, 5, 159–169.
- Jolles, J., & Hijman, R. (1983). The neuropsychology of aging and dementia. In W. H. Gispen & J. Traber (Eds.), *Aging of the brain* (pp. 227–250). New York: Elsevier.
- Lafèche, G., & Albert, M. (1995). Executive function deficits in mild Alzheimer's disease. *Neuropsychology*, 9, 313–320.
- LeThiec, F., Jokic, C., Enot-Joyeux, F., Durand, M., Lechavalier, B., & Eustache, F. (1999). Evaluation écologique des fonctions exécutives chez les traumatisés crâniens graves: Pour une meilleure approche du handicap. *Annales de Réadaptation Médicale et Physique*, 42, 1–18.
- Levin, H. S., Fletcher, J. M., Kufera, J. A., Harward, H., Lilly, M. A., Mendelsohn, D., Bruce, D., & Eisenberg, H. M. (1996). Dimensions of cognition measured by the Tower of London and other cognitive tasks in head-injured children and adolescents. *Developmental Neuropsychology*, 12, 17–34.
- Luria, A. R. (1966). *Les fonctions corticales supérieures de l'homme*. Paris: Presse universitaires de France.
- Luria, A. R. (1969). Frontal syndromes. In P. J. Vinken & G. W. Bruyn (Eds.), *Handbook of clinical neurology* (pp. 725–757). Amsterdam: North-Holland.

- Luria, A. R. (1973). *The Working Brain*. New York: Penguin Press.
- Luria, A. R., & Homskaya, E. D. (1964). Disturbances in the regulative role of speech with frontal lobe lesions. In J. M. Warren & K. Akert (Eds.), *The frontal granular cortex and behavior* (pp. 353–371). New York: McGraw-Hill.
- McCarthy, R. A., & Warrington, E. K. (1990). *Cognitive neuropsychology: A clinical introduction*. New York: Academic Press.
- McKahn, G., Drachman, D., Folstein, M., Katzman, R., Price, D., & Stadlan, E. M. (1984). Clinical diagnosis of Alzheimer's disease: Report of the NINCDS-ADRA work group under the auspices of Department of Health and Human Services Task Force on Alzheimer's disease. *Neurology*, 34, 939–944.
- Milner, B. (1964). Some effects of frontal lobectomy in man. In J. M. Warren & K. Akert (Eds.), *The frontal granular cortex and behavior* (pp. 313–334). New York: McGraw-Hill.
- Milner, B. (1982). Some cognitive effects of frontal lesions in man. *Philosophical Transactions of the Royal Society of London*, 298, 211–226.
- Owen, A., Downes, J. J., Sahakian, B. J., Polkey, C. E., & Robbins, T. W. (1990). Planning and spatial working memory following frontal lobe lesions in man. *Neuropsychologia*, 28, 1021–1034.
- Passini, R., Rainville, C., Marchand, N., & Joanne, Y. (1995). Wayfinding in dementia of the Alzheimer type: Planning abilities. *Journal of Clinical and Experimental Neuropsychology*, 17, 820–832.
- Patterson, M. B., Mack, J. L., Gelmacher, D. S., & Whitehouse, P. J. (1996). Executive functions and Alzheimer's disease: Problems and prospects. *European Journal of Neurology*, 3, 5–15.
- Pennington, B. F. (1994). The working memory function of the prefrontal cortices: Implications for developmental and individual differences in cognition. In M. M. Haith, R. R. J. Benson, & B. F. Pennington (Eds.), *Future oriented processes in development* (pp. 243–292). Chicago: University of Chicago Press.
- Pennington, B. F., Bennetto, L., McAleer, O., & Roberts, R. J. (1996). Executive functions and working memory. In G. R. Lyon & N. A. Krasnegor (Eds.), *Attention, memory, and executive function* (pp. 327–348). Baltimore: Brookes Publishing.
- Perry, J. R., & Hodges, J. R. (1999). Attention and executive deficits in Alzheimer's disease: A critical review. *Brain*, 122, 383–404.
- Petrides, M. (1985). Deficits on conditional associative-learning tasks after frontal- and temporal-lobe lesions in man. *Neuropsychologia*, 23, 601–614.
- Rainville, C. (1992). *Les troubles de la représentation anticipatrice et de la représentation spatiale dans la maladie d'Alzheimer*. Dissertation, University of Montreal.
- Roman, G. C., & Royall, D. R. (1999). Executive control function: A rational basis for the diagnosis of vascular dementia. *Alzheimer Disease and Associated Disorders*, 13, 69–80.
- Royal, D. R. (1994). Precipitous of executive dyscontrol cause of problem behavior in dementia. *Experimental Aging Research*, 20, 73–94.
- Royal, D. R., Mahurin, R. K., & Cornell, J. (1994). Bedside assessment of frontal degeneration: Distinguishing Alzheimer's disease from non-Alzheimer's cortical dementia. *Experimental Aging Research*, 20, 95–103.
- Sahakian, B. J., Downes, J. J., Eagger, S., Evenden, J. L., Levy, R., Philpot, M. P., Roberts, A. C., & Robbins, T. W. (1990). Sparing of attentional relative to mnemonic function in a subgroup of patients with dementia of the Alzheimer type. *Neuropsychologia*, 28, 1197–1213.
- Shallice, T. (1982). Specific impairment of planning. *Philosophical Transactions of the Royal Society of London*, 298, 199–209.
- Shallice, T., & Burgess, P. (1991). Deficits in strategy application following frontal lobe damage in man. *Brain*, 114, 727–741.
- Simes, R. J. (1986). An improved Bonferroni procedure for multiple tests of significance. *Biometrika*, 73, 751–754.
- Spieler, D. H., Balota, D. A., & Faust, M. E. (1996). Stroop performance in healthy younger and older adults and in individuals with dementia of the Alzheimer type. *Journal of Experimental Psychology: Human Perception and Performance*, 22(2), 461–479.
- Stouffer, S. A., Guttman, L., Suchman, E. A., Lazarfeld, P. F., Star, S. A., & Clausen, J. A. (1950). *Measurement and prediction*. Princeton: Princeton University Press.
- Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, 18, 643–662.

- Strub, R. I., & Black, F. W. (1981). Alzheimer's/senile dementia. In R. I. Strub & F. W. Black (Eds.), *Organic brain syndromes* (pp. 119–164). Philadelphia: F.A. Davis.
- Stuss, D. T., & Benson, D. E. (1986). *The frontal lobes*. New York: Raven Press.
- Van der Linden, M. (1994). Neuropsychologie de la mémoire. In X. Seron & M. Jeannerod (Eds.), *Traité de neuropsychologie humaine* (pp. 282–316). Bruxelles: Mardaga.
- Welsh, M. C., Pennington, B. F., & Groisser, D. B. (1991). A normative-developmental study of executive function: A window on prefrontal function in children. *Developmental Neuropsychology*, 7, 131–149.
- Willis, S. L., Allen-Burge, R., Dolan, M. M., Bertrand, R. M., Yesavaga, J., & Taylor, I. L. (1998). Everyday problem solving among individuals with Alzheimer's disease. *Gerontologist*, 38, 569–577.