

Study of Verbal Working Memory in Patients With Parkinson's Disease

Brigitte Gilbert

Institut Universitaire de Gériatrie de Montréal

Sylvie Belleville

Institut Universitaire de Gériatrie de Montréal and Université de Montréal

Louis Bherer

Institut Universitaire de Gériatrie de Montréal and Université du Québec à Montréal

Sylvain Chouinard

Centre Hospitalier Universitaire de Montréal

The authors examined the nature of the working memory deficit in persons with Parkinson's disease (PD). Three hypotheses were tested: a limited storage capacity, an impaired executive component, and a reduction of psychomotor speed. Verbal working memory was assessed in 14 PD patients without dementia and 14 matched control participants. Participants were administered a classical verbal span test, working memory tasks that required either updating or manipulation capacities, and motor and psychomotor speed tasks. Patients' performance was comparable to that of control participants on the verbal span test. However, results on the working memory tasks indicated a deficit in manipulation with normal updating capacities. Motor and psychomotor slowing were found in the patient group, but slowing could not fully account for the impairment observed in the manipulation task. Results indicated that there is a genuine but selective working memory impairment in patients with PD.

Parkinson's disease (PD) is a neurodegenerative disorder characterized by resting tremors, rigidity, bradykinesia, and postural instability. This neurological disease results in a loss of nerve cells in the substantia nigra and a subsequent depletion of dopamine levels in the striatum, a structure that is known to be heavily interconnected with the frontal cortex (Alexander, DeLong, & Strick, 1986). In recent years, *working memory* (WM), broadly defined as a temporary system that stores and processes online information (Baddeley, 1986; Goldman-Rakic, 1995; Petrides, 1995), has been studied extensively in patients with PD. The study of WM in this population was motivated by neuroimaging studies implicating the prefrontal cortex in WM (D'Esposito et al., 1995; Salmon et al., 1996) and the discovery that the disruption of pathways serving this cortical area results in a WM deficit (Owen,

Doyon, Dagher, Sadikot, & Evans, 1998). WM is involved in tasks that require attentional control functions similar to those classically defined as executive (Engle, 2002).

There are different views concerning the functional organization of WM within the prefrontal cortex. One view is that distinct portions of the lateral prefrontal cortex are specialized for the WM of different types of information (e.g., visuospatial and visual; Goldman-Rakic, 1995). Another view is that functional organization is based on the nature of processing (Owen, 2000; Petrides, 1995). In this latter view, one influential model fractionates WM into processing capacities such as manipulation and monitoring and processes involved in the maintenance of information. These different capacities are thought to rely on distinct regions of the lateral prefrontal cortex. The dorsolateral area is involved in manipulation and monitoring, and the ventrolateral area is involved in the maintenance of information.

In several studies, researchers have reported that patients with PD perform poorly on a number of verbal WM tasks. However, the exact nature of this deficit remains unclear. In this article, we assess three major hypotheses that attempt to account for this impairment. One widespread hypothesis is that the WM deficit of patients with PD is related to an impaired executive component mediated by the dorsolateral prefrontal cortex. Evidence in support of this hypothesis has been provided in clinical studies in which researchers found that to some extent, patients with PD perform similarly to frontal lobe patients on classical executive tasks (Gabrieli, Singh, Stebbins, & Goetz, 1996; R. G. Morris et al., 1988; Taylor, Saint-Cyr, & Lang, 1986; West, Ergis, Winocur, & Saint-Cyr, 1998). Furthermore, in studies using tasks derived from experimental psychology, researchers have reported impairments in WM tasks in medicated and unmedicated patients with PD. Deficits have been observed on the random generation task (Robertson, Hazlewood, & Rawson, 1996), the dual-task paradigm (serial recall and visual tracking; Dalrymple-Alford, Kalders, Jones, & Watson, 1994), the sentence and arithmetic spans (Gabrieli et al., 1996), and the backward digit span and ordering tasks (Bublak, Müller, Grön, Reuter, & von Cramon, 2002; Cooper,

Brigitte Gilbert, Centre de Recherche, Institut Universitaire de Gériatrie de Montréal, Montreal, Quebec, Canada; Sylvie Belleville, Centre de Recherche, Institut Universitaire de Gériatrie de Montréal, and Department of Psychology, Université de Montréal, Montreal; Louis Bherer, Centre de Recherche, Institut Universitaire de Gériatrie de Montréal, and Department of Psychology, Université du Québec à Montréal, Montreal; Sylvain Chouinard, Centre Hospitalier Universitaire de Montréal, Montreal.

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Correspondence concerning this article should be addressed to Brigitte Gilbert, Centre de Recherche, Institut Universitaire de Gériatrie de Montréal, 4565 Chemin de la Reine-Marie, Montreal, Quebec H3W 1W5, Canada. E-mail: Brigitte.gilbert@umontreal.ca

Sagar, Jordan, Harvey, & Sullivan, 1991). Recently, Lewis et al. (2003) provided additional support for the executive hypothesis. These researchers tested patients with PD on a WM manipulation paradigm in which participants recalled digits by rearranging them in an order that differed from the order of presentation. After dividing patients according to their score on the Tower of London task, Lewis et al. found that only poor performers were impaired on the WM task.

In contrast, other researchers have not found executive WM deficits in medicated patients with PD. For example, in one study, Fournet, Moreaud, Roulin, Naegel, and Pellat (1996) failed to obtain a significant Group \times Interference interaction on a modified version of the Brown–Peterson procedure. Furthermore, Channon (1997) did not observe an executive deficit in an updating task. This task involves the presentation of lists of consonants that vary in length. Participants are asked to report the last consonants on the list. However, because participants are not aware of the length of the list in advance, they must update their memory content by removing the earlier consonants to leave space for subsequent items as the presentation proceeds. The longer the list, the more updating is required. Inefficient executive processes in a target group typically result in a Group \times Number of Updates interaction (i.e., in a greater decrease in performance when the amount of updating increases; Van der Linden, Brédart, & Beerten, 1994). Because Channon did not obtain such an interaction, there is little support in Channon's study for the notion of impaired executive or updating processes in patients with PD.

Another possible source of the verbal WM deficit in patients with PD concerns reduced storage capacities. In the majority of experiments conducted with medicated patients, researchers have reported normal verbal storage capacity with classical span measures. In the few studies in which researchers have assessed both storage capacities and the executive component of verbal WM, they have reported inconsistent results. Fournet et al. (1996) found that there was a reduced span with normal executive processes; however, other researchers found the opposite pattern (Cooper et al., 1991; Dalrymple-Alford et al., 1994). Procedural differences may account for the conflicting findings observed across these two sets of studies. For example, Fournet et al. used a span task with a 4-s interval between item presentation and recall. Differences in patients' clinical characteristics may also account for the discrepancies in results between studies.

A somewhat different hypothesis regarding the nature of the WM deficit has been proposed by Gabrieli et al. (1996). They suggested that a dopaminergic dysfunction results in a reduction of psychomotor speed in patients with PD, leading to a decrease in complex cognitive abilities such as those required by WM tasks. Evidence in favor of this hypothesis was provided in an experiment in which these authors found that the performance of patients with PD on sentence and arithmetic spans (both of which are WM tasks) was positively correlated with their scores on the Symbol Digit Modalities Test (SDMT; Smith, 1968), a test of psychomotor speed. In contrast, Gabrieli et al. revealed that WM was not influenced by motor speed, as evaluated with the Purdue Pegboard test (Purdue Research Foundation, 1948).

On the basis of current empirical evidence, we find it difficult to draw firm conclusions about the nature of the verbal WM impairment generally reported in patients with PD, because the data are discrepant in some cases and scant in others. One explanation for

the discrepant data may pertain to the fact that researchers have not tested these different hypotheses within the same sample of patients with PD. Indeed, the samples used across studies have varied according to many factors, including severity of the disease, medication condition, presence of depression, and cognitive status. Alternatively, it is possible that executive processes are fractionable and that different WM tasks actually reflect distinct executive processes (Baddeley, 1996; Belleville, Rouleau, Van der Linden, & Collette, 2003; Miyake et al., 2000; Owen, 2000; Petrides, 1995; Stuss, Shallice, Alexander, & Picton, 1995). Some of these processes may be preserved in the PD population, whereas others may be disrupted. Thus, divergent results may be related to the fact that not all WM tasks measure the same executive component. Finally, the presence of an impairment in storage capacity, albeit in only a portion of the population, may contribute to a higher order impairment in WM tasks (Belleville, Rouleau, & Caza, 1998; Salthouse, 1996).

Our first goal in the present study was to assess verbal WM in medicated patients with PD and to test whether decrements in performance are related to a storage deficit or to an executive impairment. Our second goal was to determine whether an underlying reduction in psychomotor speed is related to the deficit. Our third goal was to measure different executive components in the same patient population. We addressed a number of critical methodological issues. First, this is the only study to date that tests the three hypotheses in the same sample of PD patients without dementia. Second, the executive tasks were constructed so as to control for storage capacity by testing participants at their own capacity level. Third, we assessed two distinct executive components: updating and manipulation processes. This allowed us to explore whether the WM deficit in patients with PD is selective, as suggested by some researchers (Channon, 1997; Fournet et al., 1996). Updating (Miyake et al., 2000) and manipulation processes have been proposed as cognitively and functionally separable executive functions (Belleville et al., 2003; Collette & Van der Linden, 2002). *Manipulation* is defined as the process of actively modifying the format of the information to be recalled, whereas *updating* refers to eliminating material from WM to leave space for new information. On the basis of previous studies conducted with different PD samples, we hypothesized that updating would be preserved but that manipulation would be impaired.

Method

Participants

The study included 14 French patients (9 women and 5 men) with idiopathic PD. The demographic and clinical characteristics of the participants are presented in Table 1. Eight patients were recruited from the Parkinson and Movement Disorder Clinic of the Institut Universitaire de Gériatrie de Montréal, and 6 were referred by neurologists. None of the patients were hospitalized, except for 1 patient who was admitted for rehabilitation following a broken pelvis.

Most patients were diagnosed by a neurologist (Sylvain Chouinard) specializing in movement disorders. None of them had undergone neurosurgery to reduce movement disorders. The mean duration of the disease was 7.29 years ($SD = 4.53$ years, range = 2–19 years). Three patients were classified at Stage I, 6 at Stage II, and 5 at Stage III of the Hoehn and Yahr (1967) severity scale. One PD patient who had unilateral PD was not on medication. Eleven patients were receiving L-dopa only or in combination with other medications, and 2 patients were taking an anticholinergic drug.

Table 1
Means, Standard Deviations, and Ranges of Demographic and Clinical Characteristics in Patients With Parkinson's Disease (PD) and Control Participants

Variable	Patients with PD (<i>n</i> = 14)			Controls (<i>n</i> = 14)		
	<i>M</i>	<i>SD</i>	Range	<i>M</i>	<i>SD</i>	Range
Age (years)	66.29	11.08	47–84	65.79	10.33	46–82
Education (years)	12.21	4.14	5–19	12.14	2.32	9–16
MMSE	29.14	1.29	27–30	29.07	1.00	27–30
MDRS	138.29	3.52	132–144	139.86	3.63	134–144
GDS	7.93	4.95	2–17	3.86	3.11	0–11

Note. MMSE = Mini-Mental State Examination; MDRS = Mattis Dementia Rating Scale; GDS = Geriatric Depression Scale.

At the time of testing, the 13 medicated patients were on stable anti-Parkinsonian medications. All medicated patients were assessed, in their on-state in contrast to off-state, within 1 to 2 hr after taking their medication. Moreover, we considered the time of day when testing patients by asking each of them during which part of the day (a.m. or p.m.) they felt cognitively more alert and by assessing them during that period.

Each patient was individually matched to a healthy control participant on sex, age, and education (see Table 1). Control participants were selected from a pool of community members who volunteered to participate in research on aging and cognition. In both groups, we excluded persons with dementia by using the cutoff score of the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975). The mean difference between the groups on this measure was not significant, $t(26) = 0.16$, $p > .05$ (see Table 1). The possibility of dementia was also ruled out with the Mattis Dementia Rating Scale (Mattis, 1976; for normative data, see Lucas et al., 1998). No group differences were found on this measure, $t(26) = -1.16$, $p > .05$ (see Table 1). Participants also completed the Geriatric Depression Scale (GDS; Yesavage et al., 1982), which measures depressive symptoms often associated with PD. We were not surprised to find that patients with PD scored significantly higher on this measure than did control participants, $t(26) = 2.60$, $p < .05$. Five patients with PD and 1 control participant presented mild depressive symptoms (scores between 11 and 20). However, on the basis of a medical interview, we found that none of the participants showed clinical signs of depression according to the *Diagnostic and Statistical Manual of Mental Disorders* (4th edition; American Psychiatric Association, 1994). To control for the group differences on the GDS, we used scores on this scale as a covariate in the data analysis. None of the participants were institutionalized, and medical histories were taken to exclude persons for whom there was evidence of stroke, head injury, alcoholism, major psychiatric disorders, or other neurological problems. None of the control participants were taking medication known to affect cognitive functions. Participants' consent was obtained, and they received financial compensation for their expenses.

Materials and Procedure

Storage Task: Digit Span

This task is an adapted version of the Forward Digit Span subtest of the Wechsler Adult Intelligence Scale (for more details, see Belleville, Peretz, & Malenfant, 1996). Participants were instructed to orally report sequences of digits that were drawn randomly from the numbers 1 to 9. The items were presented orally at a rate of one digit per second. Sequences began with two digits, and up to four trials were provided per sequence length. If participants correctly recalled the first two sequences, sequences of one digit longer were administered. For cases in which at least one error was made, two additional sequences were provided. The procedure was terminated when participants failed to report correctly at least two sequences of

a given length. The span corresponded to the longest sequence recalled correctly on at least half of the trials.

Executive Tasks

Alphabetical recall test. This test has been described in detail elsewhere (Belleville et al., 1998). Monosyllabic French words were selected that met the criteria for frequent and imaginable substantives and that were unambiguous with respect to the print-to-sound correspondence of their first letter. These words were used to create sequences of varying lengths. Words that were included in a sequence never began with the same letter and shared no phonological or semantic similarity. Moreover, special attention was devoted to controlling for manipulation requirements of the sequences of words in the alphabetical condition and to making the manipulation equivalent for the different sequence lengths. The mean word frequency was equivalent across sequence length as well as between the direct and alphabetical conditions for a given length. Finally, a word was never repeated across different sequences for a given length.

As a first step, short-term memory capacity for words was assessed with the same procedure as that used for the digit span task. The stimuli differed from those selected for the experimental lists but were chosen according to the same general criteria. Following the span measure, participants were tested in two recall conditions: direct and alphabetical. The number of words to be recalled in each condition corresponded to the participant's word span, as measured previously. Items were read at the rate of one per second, and participants were required to report the words orally. The direct condition consisted of recalling items in the same order in which they were presented. In the alphabetical condition, participants were asked to rearrange the words and recall them in alphabetical order. Thus, in the latter condition, the sequence "route, nappe, poivre" had to be recalled as "nappe, poivre, route." Participants were allowed to point to a printed question mark in place of a forgotten word to preserve the alphabetical order of the words. Ten sequences were presented in each condition, with an example provided prior to the alphabetical condition. The order of presentation of the conditions followed an ABBA design, starting with the direct condition. This was done to control for possible effects of fatigue or practice. Prior to the experiment, a short test was given to ensure that participants knew the alphabet. The proportion of correct items recalled, expressed as a percentage, was chosen as the dependent variable.

Updating memory task. This task was adapted from N. Morris and Jones (1990). The 19 monosyllabic consonants of the alphabet (the letters *W* and *Y* were excluded because they are bisyllabic in French) were used to construct sequences with the following criteria: (a) A letter was never repeated, (b) two letters that followed one another in alphabetical order never appeared after one another, (c) the letter *Z* never appeared in the last position, (d) two rhyming letters were never presented in the same sequence, (e) letters with names starting with the same phoneme were not

presented sequentially (in French, *Q-K* and *J-G*), and (f) consecutive letters sounding like words, acronyms, or abbreviations were avoided.

As a first step, span was measured for visually presented consonants. The items were shown sequentially at a rate of one consonant per second with a 15-ms interstimulus interval. Participants were asked to report the sequences orally. Participants were then tested on the experimental task. They were presented with sequences of letters and asked to recall the final letters of the sequence in the same order in which they were presented. The number of letters to be recalled corresponded to the participant's consonant span. For example, a participant with a span of 5 was asked to recall the last 5 letters of each sequence. Participants were told that four different sequence lengths would be presented. These lengths were again determined on the basis of the participant's span and corresponded to their span, span plus 2 items, span plus 4 items, and span plus 6 items. In the example above (participant with a span of 5), the sequences presented would contain 5, 7, 9, or 11 consonants, and the participant would be asked to report the last 5 items (5 corresponding to his or her span). To perform the task, participants had to update their memory content. The amount of updating increased with the size of the sequence, from 0 updates when the sequence was at span to 6 updates when the sequence was at span plus 6. It is important to note that the different lengths were presented randomly. Thus, when performing a particular trial, participants could not anticipate the length of the sequence and were required to perform online updating.

Each letter was again presented sequentially for 1 s with a 15-ms interstimulus interval. A visual signal (a question mark) prompted participants to report the stimuli. As in the previous task, a printed question mark could be used to indicate that a letter was forgotten. Four practice trial lengths were administered, followed by 20 sequences, 5 in each updating condition. The percentage of correct items recalled was used as the dependent variable.

Motor and Psychomotor Tests

Purdue Pegboard test (Purdue Research Foundation, 1948). This test measures manual speed and dexterity. It consists of placing, as rapidly as possible, round pegs into a series of vertically aligned holes in a board. Three 30-s trials were administered: one with the right hand, one with the left hand, and one with both hands. Participants' scores consisted of the total number of pegs placed in all trials.

Digit Symbol Substitution Test (DSST; Echelle d'Intelligence Ottawa-Wechsler, 1953). This task measures psychomotor speed. Participants were presented with a printed key consisting of numbers ranging from 1 to 9, with each digit matched to a different geometrical symbol. Below the key were strings of numbers with the corresponding symbols missing. The task consisted of drawing, as quickly as possible, the appropriate symbol under each number. The key was always in view of the participant. The score consisted of the total number of correctly completed targets in a 90-s period.

Reaction time (RT) tasks. The RT tasks were under the control of PsyScope (Version 1.0.1; Cohen, MacWhinney, Flatt, & Provost, 1993), which ran on a Power Macintosh 7100/80. The warning signal was a sine wave tone of 1000 Hz at 80 to 85 dB, and a black circle (diameter of 4 cm) served as the imperative signal. Participants initiated the trials and made their selections on a three-button response box (PsyScope Button Box).

The task started with the letters *O.K.* appearing in the center of a computer screen. This indicated to participants that they could start the trial by pressing the central button. At this point, an auditory warning signal occurred. Participants were required to keep pressing the central button until the occurrence of the imperative signal (the black circle). Participants reacted by quitting the home key and pressing the response button. In the simple condition, the black circle appeared in the center of the screen, and participants responded with the right response button as quickly as possible. Halfway through the block, they were instructed to respond with the left response button. In the choice condition, the target occurred to the right or left of the center of the screen, and the participant responded by pressing

the corresponding right or left button. After completing 5 practice trials on both tasks, participants completed 30 trials in the simple condition and 60 in the choice condition. Both conditions were completed twice within a single experimental session, with a 20- to 30-min interval between each testing.

Three speed scores were used on the basis of this task: an RT score, a movement time (MT) score, and a slowing score that compared the simple and choice conditions (see below). RT was an initiation RT (Jahanshahi, Brown, & Marsden, 1992) and corresponded to the time that elapsed from the occurrence of the imperative signal to the moment when participants removed their finger from the home key. RT was considered a psychomotor measure, as it has been shown to be more affected than MT by cognitive manipulation (Bherer & Belleville, 2004). MT is assumed to be an index of motor speed and was measured as the time taken to move from the home key to the response key. It corresponds to the remaining portion of the global response time when RT is removed (global response time - RT = MT). An additional psychomotor speed, the slowing score, was used because patients with PD are known to have specific disturbances in initiating movement. To control for this initiation deficit, we took advantage of the fact that both simple and choice RT scores implicate initiation but that choice RT involves additional processing. Thus, by subtracting simple RT from choice RT with the formula (choice RT - simple RT)/simple RT, we removed the initiation component of the task, leaving only the additional psychomotor processes involved in choice RT. Trials were not included in the analyses if response time was shorter than 100 ms or if the global response time was longer than 3,000 ms. The median RT and MT were used in the analysis.

Design. Participants were part of a larger study on the effects of PD on memory functions. In general, the neuropsychological battery and Purdue test were administered in Session 1. One WM task was conducted in Session 2, and the other in Session 3. The speed tasks were administered in Session 3.

Results

Storage Task

The average digit span was 6.86 ($SD = 1.51$) in patients with PD and 7.00 ($SD = 1.11$) in control participants. This small difference was not statistically significant, $t(26) = -0.29, p > .05$.

Executive Tasks

Alphabetical Recall

A preliminary analysis was conducted to compare the word span of the PD and control groups as measured in the preexperimental section of this task. The average span of the two groups (PD, $M = 4.36, SD = 1.01$; control, $M = 4.64, SD = 0.74$) was not statistically different, $t(26) = -0.85, p > .05$. A second preliminary analysis indicated that the order of presentation of the recall conditions (ABBA design) had no impact on performance. Thus, neither fatigue nor practice effects influenced the results. The data from these two orders of presentation were pooled in subsequent analyses.

Figure 1 shows the mean percentage of items recalled correctly by the PD and control groups in the direct and alphabetical conditions. An inspection of the figure indicates that the alphabetical condition yielded lower recall than the direct condition and that this effect was larger in the patients with PD. This was confirmed by performing an analysis of variance (ANOVA) with recall (direct or alphabetical) as a within-subject factor and group (PD or control) as a between-subjects factor. The analysis indi-

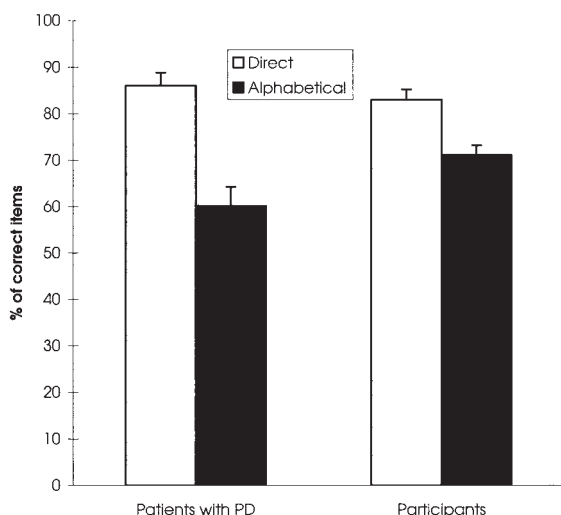


Figure 1. Percentage of items correctly recalled by patients with Parkinson's disease (PD) and control participants in conditions of direct and alphabetical recall.

cated a significant main effect of recall, $F(1, 26) = 82.39, p < .01$, and a significant Group \times Recall interaction, $F(1, 26) = 11.18, p < .01$. Simple effects indicated that the groups performed comparably in the direct recall condition ($F < 1$) but that patients with PD performed more poorly than did control participants in the alphabetical recall condition, $F(1, 26) = 5.67, p < .05$. Moreover, the effect size of the recall decrement incurred by the alphabetical condition was larger in patients with PD, $F(1, 26) = 77.14, p < .01, \eta^2 = 0.75$, than in control participants, $F(1, 26) = 16.43, p < .01, \eta^2 = 0.39$. As mentioned in the Method section, the PD group had higher scores on the GDS. Thus, we assessed whether this factor influenced performance on alphabetical recall. First, we found that the correlations between the GDS and the recall scores (direct and alphabetical) were not significant ($r = -.22, p > .05$, and $r = -.20, p > .05$, respectively). Second, use of the GDS score as a covariate in an analysis of covariance (ANCOVA) did not modify the results. Finally, a new ANOVA was conducted that excluded the 5 patients scoring above 11 on the GDS, which yielded results that were comparable to those obtained with the entire sample.

Updating Task

One PD patient (the one who was hospitalized) was not tested on the updating task because he was discharged from the hospital prior to the end of testing. Therefore, the analysis was performed on 26 participants (the control participant matched to the discharged patient was also excluded from the analysis). A preliminary analysis was conducted to compare the consonant span of each group, and this analysis indicated that they were comparable (PD, $M = 5.46, SD = 1.27$; control, $M = 5.38, SD = 0.87$), $t(24) = 0.18, p > .05$.

Figure 2 shows the mean percentage of items correctly recalled by the PD and control groups on the updating task. As can be seen in the figure, recall decreased as a function of the number of updates. However, the amount of decrease in the number of

updates was similar in both groups. This was confirmed by conducting a repeated measures ANOVA with number of updates (0, 2, 4, and 6) as a within-subject factor and group (PD or control) as a between-subjects factor. This analysis showed that neither the main effect of group nor the Group \times Number of Updates interaction reached significance ($F < 1$ in both cases; $\eta^2 = 0.023$ for the group effect and $\eta^2 = 0.014$ for the Group \times Number of Updates interaction). However, the main effect of number of updates was highly significant, $F(3, 72) = 17.20, p < .01$. Post hoc comparison tests indicated that recall was higher in updating Condition 0 relative to all other conditions and that recall was higher in updating Condition 2 relative to Conditions 4 and 6.

Motor and Psychomotor Speed Measures

A preliminary analysis of the order of presentation of the two RT tasks (simple and choice) for RT and MT scores indicated neither a main order effect nor any interaction between this variable and the other factors. Thus, the data from the two orders were pooled (for both RT and MT) in the subsequent analysis.

The amount of motor slowing was tested by comparing the performance of both groups on the Purdue test and on MT. These analyses indicated that there was motor slowing in patients with PD (see Table 2). There was a significant group difference on the Purdue test, $t(26) = -5.47, p < .01$. Moreover, a repeated measures ANOVA conducted on MT with condition (simple or choice) as a within-subjects factor and group (PD or control) as a between-subjects factor revealed a main effect of group, $F(1, 26) = 15.51, p < .01$. A main effect of condition was also found, $F(1, 26) = 39.93, p < .01$, as MT was faster in the simple than in the choice condition. There was no Group \times Condition interaction ($F < 1$). The group differences remained significant for both tasks when the results were adjusted for depression scores (ANCOVA with GDS as covariate).

Slowing was also found in patients with PD when performance on the psychomotor speed measures (DSST, RT, and slowing

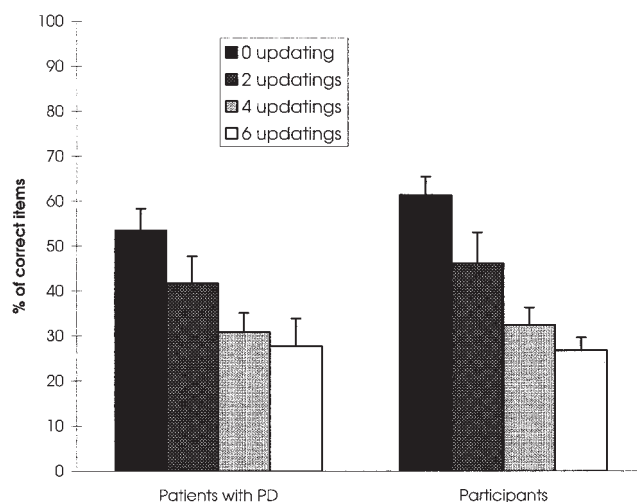


Figure 2. Percentage of items correctly recalled by patients with Parkinson's disease (PD) and control participants as a function of the number of updates.

Table 2
Means, Standard Deviations, and Ranges of Motor Speed and Psychomotor Speed Variables in Patients With Parkinson's Disease (PD) and Control Participants

Variable	Patients with PD (<i>n</i> = 14)			Controls (<i>n</i> = 14)		
	<i>M</i>	<i>SD</i>	Range	<i>M</i>	<i>SD</i>	Range
Motor speed						
Purdue	35.07	8.70	17–48	50.50	5.96	39–58
Reaction time task (MT)						
Simple	268.79	90.71	148–492	159.96	65.04	78–301
Choice	339.11	93.23	184–478	217.18	75.67	83–318
Psychomotor speed						
DSST	38.93	16.16	9–68	49.07	11.54	25–60
Reaction time task (RT)						
Simple	405.21	78.57	296–547	313.71	61.19	250–488
Choice	464.68	76.18	337–599	384.43	70.80	276–571

Note. MT = movement time; DSST = Digit Symbol Substitution Test; RT = reaction time.

score) were analyzed (see Table 2). Patients with PD performed more poorly on the DSST than did control participants, although this difference only approached statistical significance, $t(26) = -1.91, p = .07$. A repeated measures ANOVA was conducted on RT using condition (simple or choice) as a within-subjects factor and group (PD or control) as a between-subjects factor. A group effect was obtained, $F(1, 26) = 10.71, p < .01$, as well as a main effect of condition, as responses were slower in the choice than in the simple condition, $F(1, 26) = 81.75, p < .01$. There was no Group \times Condition interaction ($F < 1$). When using the slowing score as a dependent variable, we found no difference between the control ($M = 0.233$ ms, $SD = 0.134$ ms) and PD ($M = 0.157$ ms, $SD = 0.106$ ms) groups, $t(26) = -1.67, p > .05$, suggesting that an initiation deficit may account for psychomotor slowing in patients with PD. The analysis was repeated as an ANCOVA with GDS score as a covariate. RT continued to differ across groups, $F(1, 25) = 6.48, p < .05$.

Correlational analyses were conducted to test whether psychomotor slowing could account for reduced verbal WM. Specifically, we assessed whether the reduced performance on the alphabetical recall task for the PD group was related to psychomotor speed measures. To test this hypothesis, we derived a manipulation cost score according to the following formula: (direct score – alphabetical score)/direct score. If the psychomotor slowing account is true, this manipulation score is expected to be correlated negatively with the DSST and positively with the slowing score and RT measures. In turn, no such relations should be found with motor measures. The correlations between the manipulation cost score and the DSST, RT, and slowing score were in the right direction, and some were moderately high. However, they failed to reach significance ($r_s = -.44, .25, .49$, and $.34, p_s > .05$, for the DSST, the simple and choice RT conditions, and the slowing score, respectively). There was no significant correlation between the manipulation cost score and motor speed measures (Purdue test, $r = -.19$; simple MT, $r = .26$; choice MT, $r = -.02$; $p_s > .05$). Finally, an ANCOVA on the alphabetical recall data (group as a between-subjects factor and recall as a within-subjects factor), with the different psychomotor measures used as a covariate, did not change the results.

WM Task Performance, Disease Severity, Age, and Medication

Because it has been suggested that the severity of PD contributes to the extent of WM impairment (Owen, Iddon, Hodges, Summers, & Robbins, 1997), we performed a corollary analysis by separating patients into two subgroups according to the Hoehn and Yahr scale (1967). Specifically, the mild to moderate group (Stages I–II) and severe group (Stage III) included 9 and 5 patients, respectively (8 and 5 for the updating task). An ANOVA performed on the alphabetical recall task revealed no main effect of group ($F < 1$), nor a Group \times Recall interaction, $F(1, 12) = 1.88, p > .05$. A similar pattern of results was obtained with an ANOVA conducted on the updating task: group effect, $F(1, 11) = 3.33, p > .05$; and Group \times Number of Updates interaction, $F < 1$.

We also divided the PD patients by age using a median split: Group 1 ($n = 7, M$ age = 56.86 years) and Group 2 ($n = 7, M$ age = 75.71 years; for the updating task, $n = 6, M$ age = 74.33 years). An ANOVA conducted on the alphabetical recall task revealed no main effect of group, $F(1, 12) = 3.28, p > .05$, and no Group \times Recall interaction ($F < 1$). Furthermore, neither the group effect nor the Group \times Number of Updates interaction was significant ($F_s < 1$) when an ANOVA was conducted on the updating task.

Finally, because 2 patients were receiving anticholinergic medication, an ANOVA on the alphabetical recall task was repeated with these patients excluded to assess the potential negative impact of this medication. Results remained unchanged, as the interaction was still significant, $F(1, 24) = 13.24, p < .01$, with no group effect ($F < 1$).

Discussion

Our goal in this study was to assess the nature of the verbal WM deficit in persons with PD. The major findings can be summarized as follows. First, the results indicate that our group of patients with PD has intact verbal short-term storage, as measured with a typical span task. Second, an executive deficit in performance was evident on a task that controlled for storage capacity. Third, this executive deficit is selective: A decrease in performance was obtained on a

task requiring manipulation processes; however, normal performance was found on a test implicating updating processes. Fourth, psychomotor and motor speed were decreased in the PD participants compared with the control group.

These results are unrelated to dementia, depression, age, or educational level. None of our patients showed significant cognitive deterioration on two tests of mental status (Mini-Mental State Examination and Mattis Dementia Rating Scale). Furthermore, although an increase in GDS scores was present in patients with PD, none of them were clinically depressed. Covarying this factor with alphabetical recall or speed measures did not modify the results of these analyses. Because the patients with PD were matched to control participants on age and educational level, it is unlikely that these factors influenced the results obtained on the executive tasks. Finally, statistical analyses did not reveal an impact of disease progression on executive measures. The present data is discussed below in light of three main hypotheses regarding the nature of WM impairment: a limitation of storage capacity, a decrease in psychomotor speed, and a deficit in the executive component of WM.

The hypothesis that a WM deficit is related to a decrease in short-term capacity is inconsistent with the current findings. As a group, patients with PD did not show evidence of a reduced storage capacity. This finding was obtained with different types of material: digits, consonants, and words. The majority of studies that have assessed verbal short-term capacity have reported normal performance in patients with PD (Bradley, Welch, & Dick, 1989; Cooper et al., 1991; Dalrymple-Alford et al., 1994). Thus, our results are consistent with these findings.

One exception to this rule are the data of Fournet et al. (1996), who reported storage deficits in patients with mild to moderate PD. However, span was not evaluated in a standard manner in their study, because an interval of 4 s preceded the recall. It is possible that the classical span measures used in the present study lack the sensitivity to reveal subtle storage deficits, or rapid forgetting, which can be found only in delayed conditions. It is also possible that the task used by Fournet et al. involved executive capacities that may be necessary to hold or rehearse digits during the interval (Belleville et al., 1996; R. G. Morris, 1986; Rypma, Prabhakaran, Desmond, Glover, & Gabrieli, 1999). Thus, the deficit observed in Fournet et al. may reflect an executive impairment as opposed to a deficit in basic storage.

A second hypothesis is that a decrease in psychomotor speed underlies the WM impairment of patients with PD (Gabrieli et al., 1996). The present study partially supports this assertion. There were correlations between the manipulation cost score and the psychomotor speed measures; however, these failed to reach significance. A lack of power related to the small number of patients may have prevented correlations from reaching significance, particularly for the choice RT and DSST speed tasks, which were reasonably sized. Moreover, the fact that we adjusted WM performance for storage capacity may have prevented us from obtaining strong correlations between manipulation cost scores and psychomotor speed scores if the latter acts on storage capacities. Equating WM tasks on the basis of patients' storage capacity has been conducted to control for a potential contribution of impaired elementary processes on tasks assessing higher level processes, such as executive ones. Psychomotor speed may have been one of these elementary processes. Of importance, the possibility that a

general speed factor is linked to some of the WM performance in PD does not preclude the contribution of more specific factors. Some researchers (Keys & White, 2000; Salthouse, 1996) have suggested that general factors (e.g., speed) may coexist with specific ones (e.g., executive). We find it interesting that manipulation capacities remained impaired in participants with PD after experimental control for basic storage and possibly speed. Furthermore, statistically controlling for psychomotor speed by using it as a covariate did not modify the Group \times Recall interaction on the alphabetical recall task. Thus, it is probably reasonable to conclude that if psychomotor speed is related to WM performance, this factor cannot on its own explain the entire difference observed on the manipulation task. The presence of an executive component deficit in WM tasks may be one of the specific factors that also explains verbal WM deficits in PD.

A major hypothesis concerning the WM deficit in patients with PD is that the executive component is impaired in this population (Bublak et al., 2002; Cooper et al., 1991; Dalrymple-Alford et al., 1994; Gabrieli et al., 1996; Owen et al., 1992, 1993, 1997; Robertson et al., 1996). Our study partially confirms this hypothesis, as we found impaired performance in the manipulation condition of the alphabetical recall task. Of importance, and in contrast to the majority of studies, the present executive tasks were adjusted to suit individuals' short-term storage capacity, a procedure that isolates the specific contribution of the executive component. Our results confirm and complement recent findings indicating that patients with PD are impaired on different WM tasks requiring the manipulation of information (Bublak et al., 2002; Cooper et al., 1991). However, our results also reveal that updating mechanisms are unaffected by the disease. This is consistent with Channon's (1997) results, which are also indicative of normal updating capacities in patients with PD when individual performance is not adjusted to span capacities. These results suggest that the lack of an updating deficit in patients with PD is unrelated to procedural issues or differences in populations.

Taken together, results on the manipulation and updating tasks reveal a dissociation within executive WM processes. With the present study, we are the first to report an executive WM dissociation in a single group of patients with PD. This is important because it indicates that the executive problem of these patients is not pervasive: There are components of the WM executive system that are less vulnerable to the disease process. The dissociation that we observed is compatible with current knowledge about the neuropathological basis of PD. According to Alexander et al. (1986), five distinct pathways connect the frontal cortex to the basal ganglia. Among these, the dorsolateral pathway has been implicated in cognitive functions and is thought to be damaged early in PD (Gabrieli et al., 1996). Results from normal brain mapping studies are consistent with the hypothesis that manipulation and updating tasks involve neurologically distinct systems. The bilateral–prefrontal–dorsolateral cortex has been implicated in alphabetical recall (Collette et al., 1999), which is impaired in patients with PD. In contrast, updating activity, which is preserved in patients with PD, predominantly implicates the left frontopolar cortex (Van der Linden et al., 1999).

At a theoretical level, the dissociation between these two processes in PD tends to support the conceptual view that the executive component is fractionable both at a neural and a cognitive level (Baddeley, 1996; Belleville et al., 2003; Miyake et al., 2000;

Owen, 2000; Petrides, 1995; Shallice & Burgess, 1993; Stuss et al., 1995). Similar partial impairment has been found on classical tests of executive function in this population (Gurd, 1995; Richards, Côté, & Stern, 1993), and it remains to be determined whether this is related to the particular dissociation observed here.

Although the selective impairment of executive processes that leads to the present dissociation may be promising in terms of explaining the cognitive deficits related to PD, methodological limitations of the data must be considered. For example, it is possible that differences in task sensitivity can explain the observed dissociation. Indeed, one could argue that the two tasks measure the same WM component but that the updating task is easier than the manipulation task. This interpretation would be consistent with Brown and Marsden's (1991) suggestion that these patients suffer from reduced attentional resources and that their deficit is largely determined by the attentional demand of the tasks.

Even if the argument of task sensitivity cannot be refuted completely, it is unlikely that this issue alone can account for the present findings. If the updating task is simply an easier test than alphabetical recall, performance should always be less impaired on the updating task, irrespective of the population. There are empirical data showing that this is not the case. In similar paradigms, healthy older persons showed impaired updating capacities (Van der Linden et al., 1994) and intact alphabetical recall (Belleville et al., 1998). One must acknowledge that only one task was used to assess each functional component. Although we replicated Channon's (1997) finding, the use of a slightly different version of an updating task might have resulted in impaired performance in patients with PD. Finally, the dissociation found in the present study is based on experimental tasks, and its ecological validity and relevance to complex activities of daily life remain to be assessed.

One may argue that adjusting the storage level of the executive tasks changed the nature of the task demands. This methodological control was motivated by the possibility of a storage deficit in patients with PD and also by the importance of obtaining as pure an executive measure as possible. Modest storage reduction can substantially modify the pattern of results even if the groups obtained comparable means on span measures (Belleville et al., 1998). This methodological constraint was necessary to isolate the executive component in these WM tasks.

Finally, the potential role of medication must be considered. First, 2 patients were taking anticholinergic medication, but removing them from the analyses had no effect on the outcome. Second, studies have demonstrated that dopaminergic medication can improve WM performance (Cooper et al., 1992; Costa et al., 2003; Fournet, Moreaud, Roulin, Naegele, & Pellat, 2000). This is relevant here because the majority of our patients were receiving L-dopa. Of importance, the beneficial effect of dopaminergic therapy on WM does not extend to manipulation, because our patients were impaired on that component in spite of being on medication. We did not find an updating deficit in medicated patients. It is unclear whether this normal functioning is also present in unmedicated patients or whether L-dopa actually had a beneficial impact on updating. If the latter is true, it would suggest a selective benefit of L-dopa on WM updating but not on WM manipulation. This again would support the notion that these tasks or components rely on different frontostriatal circuits.

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