Impaired updating ability in drivers with Parkinson’s disease

Maud Ranchet,1 Laurence Paire-Ficout,1 Claude Marin-Lamellet,1 Bernard Laurent,2,3 Emmanuel Broussolle4,5

ABSTRACT

Objective Driving activity requires major involvement of executive functions. The main objective of our study was to determine whether mental flexibility and the updating of information in working memory are affected in drivers with mild to moderate Parkinson’s disease (PD).

Methods The study included 25 patients, aged 58–76, with mild to moderate PD and 25 healthy controls matched for age, sex and education, with an average mileage of over 3000 km/year. Neuropsychological tests were conducted to assess global cognitive abilities, to evaluate updating (via the n-back task), flexibility (via the minus task or in the simulator task evaluating information-processing speed) and to brake at the same time as the car ahead (information-processing speed task) while driving.

Results An updating impairment was found in PD patients in the n-back and simulator tasks; patients recalled significantly fewer road signs. No notable differences were observed between groups in the plus-minus task or in the simulator task evaluating flexibility. There was no significant difference between patients and controls in information-processing speed tasks. Regression analysis showed that the Trail-Making test (B-A) accounted for 40.7% of the variation in PD patients and controls in information-processing speed.

Conclusion The updating function is clearly impaired in drivers with mild to moderate PD, while mental flexibility remains unaffected. This study demonstrates the interest of using the Trail Making Test and simulator tasks to assess PD drivers.

INTRODUCTION

Parkinson’s disease (PD) is a progressive neurological disorder characterised by both motor and non-motor symptoms. Cognitive symptoms are a major feature which can appear even in the early stages of PD.1 2 Impairments of working memory and executive functions are frequently observed,2 3 as are disturbances in high-level executive functions such as planning and problem solving.4 5 Deficits are also described in lower-level executive functions such as mental flexibility (set shifting),6 7 inhibition of automatic responses7 and the manipulation and updating of verbal and visuospatial representations.3 5 8 These functions are all particularly important in novel, dynamic or demanding situations.9 and most driving scenarios fall into this category.10 Updating, for instance, is particularly important for refreshing information such as road signs. Mental flexibility is also essential for adapting driving behaviour to changing contexts on the road11 where operations must be performed quickly, within a time frame.

PD patients may give up driving at some point in the course of the disease,12 but they often continue to drive during the first decade of their illness.13–15 Although there are no well-established epidemiological data on the crash risk for this population,16 an increased risk of accidents has been reported in PD.17 18 For the above reasons, a better understanding of the relationship between cognitive and driving abilities is necessary in order to identify patients whose driving abilities may be potentially impaired.19

The main objective of this study was to determine whether executive functions such as updating of information in working memory and mental flexibility are affected in drivers with mild to moderate PD. To do so, neuropsychological tests and specific tasks using a driving simulator were used. To our knowledge, no study has hitherto investigated these functions independently using simulated driving in this population. Information-processing speed was also measured, since a slowing of this ability could well explain poorer performances in PD patients.20 Our secondary objective was to examine the impact of updating and flexibility tasks on mean speed and speed variability. A further aim was to provide cognitive tools to assist clinicians in evaluating drivers with PD.

METHODS

Subjects

Twenty-five patients with PD (age range 58–76 years) and 25 healthy controls matched for sex, age, education level and driving experience were included in the study (table 1).

The sex ratio was 19 men/6 women in both groups. PD patients were recruited by a neurologist (EB) at the Department of Neurology. The following exclusion criteria were applied for patients: treatment with anticholinergic medication; global cognitive deterioration based on a score of 24 or less in the Mini Mental State Examination; moderate to severe depression based on a clinical interview and a score of 17 or more in the Beck Depression Inventory; and presence of neurological disorders other than idiopathic PD. Inclusion criteria were as follows: idiopathic PD according to the UK’s Parkinson’s Disease Brain Bank standards,21 normal visual acuity. Patients were in the mild to moderate stages of PD, based on disease duration, the Hoehn and Yahr scale and the motor section of the Unified Parkinson’s Disease Rating Scale (UPDRS). Patients

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were assessed while on medication. Thirteen patients were rated at Hoehn and Yahr stage 1.5, 10 at stage 2, 1 at stage 2.5 and 1 at stage 5. Twenty PD patients were treated by levodopa; 9 (45%) had mild to moderate motor fluctuations. Overall, 18 patients were on dopamine agonists ( pergolide, pramipexole, ropinirole, piribedil), 5 were on COMT inhibitors ( entacapone), 2 on MAO inhibitors ( selegiline) and 1 on amantadine. One patient had to name the colour of each rectangle as quickly as possible. This condition was designed to evaluate information-processing speed.

### Mental flexibility: the plus—minus task

On the first list, participants were instructed to add 3 to each number and write down their answers. On the second list, they were instructed to subtract 3 from each number. On the third list, the participants were required to alternate between adding 3 and subtracting 3 from the numbers. We used shift cost as a measure of mental flexibility, calculated as being the difference between mean completion times of the third list and mean completion times from the first two lists.

### Information-processing speed: Stroop test

In the colour-naming condition of the Stroop test, participants had to name the colour of each rectangle as quickly as possible.

### Table 1 Demographic and clinical characteristics of Parkinson's disease patients and controls

<table>
<thead>
<tr>
<th></th>
<th>Parkinson's disease patients, n = 25, mean (SD)</th>
<th>Controls, n = 25, mean (SD)</th>
<th>Two-tailed p-value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>65.4 (5.2)</td>
<td>66.7 (4.4)</td>
<td>0.325</td>
</tr>
<tr>
<td>Years of education</td>
<td>13.9 (3.7)</td>
<td>13.6 (2.8)</td>
<td>0.937</td>
</tr>
<tr>
<td>Years of driving</td>
<td>45.1 (6.0)</td>
<td>46.6 (6.1)</td>
<td>0.533</td>
</tr>
<tr>
<td>Mini Mental State Examenation (MMSE) score</td>
<td>28.1 (1.4)</td>
<td>29.1 (0.9)</td>
<td>0.006</td>
</tr>
<tr>
<td>Beck Depression Inventory score</td>
<td>9.0 (4.7)</td>
<td>6.0 (2.6)</td>
<td>0.008</td>
</tr>
<tr>
<td>Epworth Sleepiness Scale score</td>
<td>7.2 (2.9)</td>
<td>6.1 (3.3)</td>
<td>0.223</td>
</tr>
<tr>
<td>Hoehn and Yahr stage</td>
<td>1.8 (0.4)</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Disease duration in years</td>
<td>6.4 (5.4)</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Disease onset age in years</td>
<td>58.9 (7.7)</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Unified Parkinson's disease Rating Scale—motor score</td>
<td>14.9 (5.2)</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Levodopa dosage (mg/day)†</td>
<td>346.5 (267.7)</td>
<td>--</td>
<td></td>
</tr>
</tbody>
</table>

Values in bold are significant.
*Student t test or Mann—Whitney U test.
†Levodopa (+dopa-decarboxylase inhibitor) without dopaminergic agonists.

### Neuropsychological assessments

Neuropsychological testing was conducted to investigate the various cognitive processes related to driving abilities, with particular focus on updating, mental flexibility and information-processing speed.

### Global cognitive assessment

Measures of global executive function were obtained using the Trail Making Test (TMT B—A). The ability to inhibit an automatic response, visual memory and short-term storage capacity were assessed via the Stroop test (inhibition cost index), Benton Visual Retention Test and a digit span task, respectively. Maintenance of relevant information (phonological loop), was measured using Baddeley’s Working Memory digit-span task in single condition, in which participants were required to recall digits sequences of the same length for 2 min.

### Updating: n-back task

This computerised task included three conditions: in the control condition (0-back), participants were asked to respond as quickly as possible on presentation of the number 50. In the two remaining conditions, they had to evaluate the similarity of each item to the one presented n-items previously (n being a pre-specified integer (n=1, n=2)). Correct response times and errors were measured in each condition. In our study, the 2-back condition was taken as a measure of updating ability.

### Driving simulator and experimental tasks

The experiment was conducted using the INRETS fixed-base simulator, a Renault Espace car with a manual gearbox, with hidden instrumentation and sensors. The vehicle has a three-screen front view with a horizontal visual field of 150° and a vertical visual field of 40° (figure 1). Before performing the driving test, subjects were invited to familiarise themselves with the simulator by driving it for 20 min. Three scenarios were developed to assess updating, mental flexibility and information-processing speed while driving.

### Updating task

In this task (a 24 km scenario), participants were asked to recall, in any order, the last three road signs of each series while driving (free recall). They subsequently had to answer different questions about information given on the last three road signs (cued recall). Three series of four, six or eight road signs respectively varied randomly. The updating score, calculated as adding the free recall and cued recall scores, represented our updating measure (figure 2).
Driving speed and speed variability
Mean driving speed and speed variability (mean SD of speed) were measured in both updating and flexibility tasks. According to the literature, slow speed associated with high speed variability are indicative of decreased driving ability. A reduction in speed variability is interpreted as an adaptation of driving behaviour when a concurrent task is present.

Procedure
The experimental part of the study was divided into two phases for all participants. In phase 1, they were examined by a general medical practitioner in order to verify medical inclusion criteria. In phase 2, on a separate day, neuropsychological simulated driving tests were carried out in a fixed order over a period of 3 to 4 h with two rest breaks. Driving simulator experiments lasted approximately 20 min for the updating task, 30 min for the flexibility task and 5 min for the braking task. PD patients were tested in the morning while on medication. There was approximately 1 month between neurological testing of patients and their inclusion in the study. The time between inclusion and the experiment was approximately 1 month for both patients and controls.

Data analysis
Differences between the PD and control groups regarding demographic and clinical data were analysed using an independent two-tailed Mann–Whitney U. Differences between the two groups regarding neuropsychological and driving simulator data were analysed using an independent one-tailed t test or Mann–Whitney U, depending on variable normality (Shapiro–Wilk test). In the n-back task, reaction times and errors were analysed using repeated-measure ANOVAs with group as the between-subjects factor (patients/controls), and condition as the within-subjects factor (0-back/1-back/2-back).

We used the Wilcoxon test to compare mean speed and speed variability performances between the flexibility task (condition with alternation) and the updating task. We also compared mean speed and speed variability performances in the condition without alternation to that of the condition with alternation, again using the Wilcoxon test, in order to investigate the effect of flexibility on driving performance.

Spearman correlation coefficients between UPDRS motor scores and updating scores, and flexibility and information-processing costs were calculated to ensure the absence of any association between motor functions and cognitive performances. Correlation analyses (Pearson product moment correlation and Spearman rank correlation coefficient) were used to measure the association between the neuropsychological variables and on-simulator updating scores for all participants. All significant correlated variables were then introduced into a stepwise regression analysis in order to determine which variables explain the variation in updating score for the simulator updating task for PD patients.

An α-level of 0.05 was applied to all our statistical analyses. All analyses were performed with SPSS 17.0 statistical software (SPSS, Chicago, Illinois).
RESULTS

Neuropsychological performances

In the light of neuropsychological results, the cognitive status of patients did not appear to be significantly impaired compared with controls (table 2). Global executive function (TMT), inhibition (Stroop-inhibition cost index) and verbal short-term storage (digit span) did not differ between PD patients and controls.

Updating: n-back task

ANOVA results showed that reaction times were significantly slower in patients (538.72 ms ± 95.04) than in controls (489.70 ms ± 70.25) (F(1,48) = 4.32, p = 0.043). However, patients did not commit significantly more errors than controls (patients: 1.91 ± 2.59 vs controls: 0.56 ± 0.72). Specifically, participants were significantly slower and committed more errors when the level of complexity increased (for reaction times: F(2,48) = 83.73, p < 0.001; for errors: F(2,48) = 15.53, p < 0.001). This was confirmed by a significant group × condition interaction for reaction times (F(2,48) = 5.35, p = 0.025) and for errors (F(2,48) = 5.16, p = 0.028). PD patients and controls did not differ in the 0-back condition for reaction times and errors. In the 1-back condition, no significant difference in reaction times was observed between the two groups, although patients committed significantly more errors. In the 2-back condition, the mean reaction time for PD group was significantly slower than that of the control group (F(1,48) = 4.79, p = 0.033). Similarly, the mean error for PD group was significantly higher than in the control group (F(1,48) = 5.15, p = 0.030).

Flexibility: plus minus task

Although PD patients were significantly slower than controls to complete lists in all conditions, there was no significant difference between the two groups in shift cost (table 2).

Information-processing speed: Stroop test

In the Stroop colour-naming condition, the patients were not significantly impaired, compared with controls.

Performances on driving simulator tasks

Updating, flexibility and information-processing speed task performances are presented in table 3. Significant differences were recorded between the two groups for the updating score: PD patients recalled significantly fewer road signs than controls. In the flexibility task, patients were significantly slower than controls in the condition with alternation. However, flexibility cost did not differ between the two groups. Moreover, in the information-processing speed task, while patients were significantly slower in static and dynamic conditions, there was no difference in information-processing cost between the two groups.

Driving speed and speed variability

Results for mean speed and speed variability in PD and controls during updating and flexibility tasks are presented in table 4. There were no significant differences between groups except in updating task: speed variability was surprisingly lower in patients compared with controls. We further examined the effect of updating and flexibility tasks on driving speed and speed variability independently from disease effect. This showed that participants (both patients and controls) were significantly slower in static and dynamic conditions, there was no difference in information-processing cost between the two groups.

Table 2 Comparison of Parkinson’s disease patients and controls in neuropsychological tests

<table>
<thead>
<tr>
<th>Test</th>
<th>Parkinson’s disease patients, n = 25, mean (SD)</th>
<th>Controls, n = 25, mean (SD)</th>
<th>One-tailed p-value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global cognitive assessment</td>
<td></td>
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<tr>
<td>Trail making test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Part A times (s) (1)</td>
<td>44.6 (16.8)</td>
<td>45.2 (15.8)</td>
<td>0.433</td>
</tr>
<tr>
<td>Part B times (s) (2)</td>
<td>91.9 (38.1)</td>
<td>75.9 (28.3)</td>
<td>0.090</td>
</tr>
<tr>
<td>Trail Making Test (B − A) (2)−(1)</td>
<td>47.3 (36.9)</td>
<td>30.8 (20.6)</td>
<td>0.084</td>
</tr>
<tr>
<td>Stroop test − inhibition cost index</td>
<td>66.0 (33.1)</td>
<td>53.8 (22.0)</td>
<td>0.097</td>
</tr>
<tr>
<td>Benton Visual Retention Test</td>
<td>12.8 (1.5)</td>
<td>13.4 (1.3)</td>
<td>0.054</td>
</tr>
<tr>
<td>Baddeley’s Working Memory dual task</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digit Span (n)</td>
<td>5.6 (0.9)</td>
<td>6.0 (1.2)</td>
<td>0.092</td>
</tr>
<tr>
<td>Digit span task—digits sequences recalled (n)</td>
<td>6.8 (4.2)</td>
<td>7.6 (4.1)</td>
<td>0.225</td>
</tr>
<tr>
<td>Updating: n-back task</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>0-back</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Response times (ms)</td>
<td>418.2 (60.1)</td>
<td>411.4 (59.4)</td>
<td>0.688</td>
</tr>
<tr>
<td>Errors†</td>
<td>0.7 (1.5)</td>
<td>0.2 (0.4)</td>
<td>0.261</td>
</tr>
<tr>
<td>1-back</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Response times (ms)</td>
<td>464.8 (80.2)</td>
<td>425.7 (61.0)</td>
<td>0.058</td>
</tr>
<tr>
<td>Errors†</td>
<td>0.7 (1.7)</td>
<td>0.1 (0.2)</td>
<td>0.038</td>
</tr>
<tr>
<td>2-back</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Response times (ms)</td>
<td>733.5 (189.1)</td>
<td>632.1 (133.8)</td>
<td>0.033</td>
</tr>
<tr>
<td>Errors†</td>
<td>4.4 (1.2)</td>
<td>1.4 (0.5)</td>
<td>0.002</td>
</tr>
<tr>
<td>Flexibility: plus minus task</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Addition list completion times (s)</td>
<td>60.4 (16.4)</td>
<td>50.8 (12.7)</td>
<td>0.013</td>
</tr>
<tr>
<td>Subtraction list completion times (s)</td>
<td>83.7 (29.5)</td>
<td>65.4 (22.8)</td>
<td>0.005</td>
</tr>
<tr>
<td>Shift list completion times (s) (7)</td>
<td>92.7 (31.2)</td>
<td>77.3 (19.6)</td>
<td>0.043</td>
</tr>
<tr>
<td>Shift cost (7)−[6]+(5)/2</td>
<td>20.7 (15.8)</td>
<td>19.2 (14.5)</td>
<td>0.392</td>
</tr>
<tr>
<td>Information-processing speed: Stroop test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colour naming completion time (s)</td>
<td>65.0 (9.5)</td>
<td>62.2 (7.1)</td>
<td>0.217</td>
</tr>
</tbody>
</table>

Table 3 Comparison of cognitive performances in Parkinson’s disease patients and controls in driving simulator tasks

<table>
<thead>
<tr>
<th>Test</th>
<th>Parkinson’s disease patients, n = 25, mean (SD)</th>
<th>Controls, n = 25, mean (SD)</th>
<th>One-tailed p-value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driving speed and speed variability</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Updating task</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Free recall (1)</td>
<td>18.7 (4.0)</td>
<td>21.3 (3.3)</td>
<td>0.007</td>
</tr>
<tr>
<td>Cued recall (2)</td>
<td>19.4 (3.7)</td>
<td>21.8 (2.6)</td>
<td>0.006</td>
</tr>
<tr>
<td>Updating score (1)+(2)</td>
<td>38.1 (7.2)</td>
<td>43.1 (4.7)</td>
<td>0.003</td>
</tr>
<tr>
<td>Flexibility test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Condition without alternation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Response time (ms) (3)</td>
<td>2483.5 (1163.1)</td>
<td>2045.7 (953.9)</td>
<td>0.054</td>
</tr>
<tr>
<td>Condition with alternation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Response time (ms) (4)</td>
<td>2602.6 (1059.4)</td>
<td>2144.3 (848.0)</td>
<td>0.025</td>
</tr>
<tr>
<td>Flexibility cost (4)−(3)</td>
<td>119.1 (475.4)</td>
<td>98.6 (464.3)</td>
<td>0.356</td>
</tr>
<tr>
<td>Information-processing speed task</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Static condition reaction time (ms) (5)</td>
<td>695.8 (120.3)</td>
<td>639.0 (84.5)</td>
<td>0.030</td>
</tr>
<tr>
<td>Dynamic condition reaction time (ms) (6)</td>
<td>772.3 (153.7)</td>
<td>704.6 (131.1)</td>
<td>0.040</td>
</tr>
</tbody>
</table>

Variables in italics are the variables of interest. Values in bold are significant.
*Student t test or Mann–Whitney U test. One-tailed analyses were applied in accordance with our hypothesis: we expected Parkinson’s disease patients to be significantly impaired compared with controls. Two-tailed analyses did not alter our main findings [data not shown].
† One patient was excluded from the analysis because the data could not be analysed.
‡ Errors were calculated by the addition of the number of hits and false alarms.

Variables in italics are the variables of interest. Values in bold are significant.
*Student t test or Mann–Whitney U test. One-tailed analyses were applied in accordance with our hypothesis: we expected Parkinson’s disease patients to be significantly impaired compared with controls. Two-tailed analyses did not alter our main findings [data not shown].
† Two patients were excluded from the analysis because their data could not be analysed.
controls) had a significantly slower mean driving speed (82.37 ± 8.07 vs 93.61 ± 11.85) (W = −5.04 \ p < 0.01) and higher speed variability (9.56 ± 2.77 vs 4.55 ± 2.53) (W = −5.54 \ p < 0.01) in the updating task than in the flexibility task (condition with alternation). In addition, in the flexibility task, also for all participants, the mean speed did not differ between the two conditions (condition with or without alternation) whereas speed variability decreased significantly in the condition with alternation (W = −4.55 \ p < 0.01).

### Correlation analyses in PD patients

UPDRS motor scores did not correlate significantly with updating scores, flexibility cost scores and the processing cost scores. Updating scores on the driving simulator correlated significantly with the following neuropsychological variables: Stroop inhibition cost index (r = −0.515, \ p < 0.01), TMT (B−A) (r = −0.560, \ p < 0.01), plus−minus task shift cost (r = −0.571, \ p < 0.01) and reaction times in the three conditions of the n-back task (0-back: r = −0.428; 1-back: r = 0.415; 2-back: r = −0.594, \ p < 0.05). No significant correlations were obtained between Benton Visual Retention Test scores, digit span scores and TMT A scores. Subsequently, only measures which correlated significantly with updating scores were entered in the stepwise regression model. According to this model, TMT (B−A) explained 40.7% of the variation in updating score on the simulator test. The remaining variables were not sufficiently significant to be included in the model.

### DISCUSSION

The main purpose of this study was to assess the extent to which executive functions such as the updating of information in working memory and mental flexibility are affected in drivers with mild to moderate PD. Our approach was original in that it attempted to examine these functions while driving with a simulator. In this discussion, we shall first of all examine the updating impairment found in PD patients. We will go on to comment on the absence of any flexibility effect and to discuss this dissociation. Finally, we will consider the clinical implications of these results in the context of driving.

### Updating

Both neuropsychological and simulator tests revealed impaired updating in PD patients. In the n-back task, results indicated that the patients perform significantly worse than controls when working memory load increases. The fact that patients are significantly impaired on the 2-back condition is consistent with previous reports.\(^\text{32, 33}\) The results obtained on the n-back task corroborate the findings in the updating task on the simulator: patients recalled significantly fewer road signs than controls. However, the possible existence of a relationship between a deficit in updating and a slowing in information processing is not supported by the current results.\(^\text{34}\) Although patients are generally slower, the results observed on the Stroop colour-naming test and in the information-processing speed task suggest that information-processing speed was not affected in mild to moderate PD drivers compared with controls. In addition, the updating deficit in PD patients is not due to decreased storage abilities. Verbal short-term storage, measured by digit span, remains intact in our patients, and this is coherent with previous results.\(^\text{1, 3}\) Furthermore, according to Baddeley’s model of working memory,\(^\text{35−37}\) updating appears to require two independent mechanisms: the phonological loop involving the maintenance of task-related information, and a central executive component. The updating deficit observed in our study cannot be explained by an information maintenance deficit: PD patients’ digit span, as measured by Baddeley’s Working Memory dual task, is not significantly different from that of the control group. The updating deficit would appear, therefore, to stem from a central executive dysfunction. This hypothesis is consistent with our regression analysis results. Indeed, the TMT (B−A), considered in our study as a measure of global executive function, appears to be the best predictor of updating score in the simulator for PD drivers. This means that the updating task on the simulator is closely linked to the executive system. It is worth noting that the TMT is often reported as being a good predictor of driving performance\(^\text{14, 15, 29, 30}\) and driving cessation for PD drivers.\(^\text{12}\) Our research confirms the usefulness of this test for clinicians in the assessment of PD drivers.

### Flexibility

Contrary to the updating function, flexibility is found to be unimpaired in PD patients compared with controls in both the plus−minus task and the flexibility task on the simulator. A limited power due to the small sample size might explain the absence of difference between groups on tests assessing flexibility. This could also be attributed to our selective inclusion criteria. Participants were only included if they were active drivers, and most of our patients were at relatively early stages of the disease compared with those in other studies.\(^\text{6, 16, 38}\) Alternatively, our flexibility task might not be demanding enough to discriminate between the two groups. Several authors have in fact shown that an impairment in shifting only appears in PD patients when the load of attentional resources increases.\(^\text{6, 16, 38}\) The dissociation observed between updating and flexibility tends to support the conceptual view that the executive component can be fractioned.\(^\text{11, 39}\)

### Driving speed and speed variability

In addition to cognitive performance obtained on driving simulator tasks (eg, total recall score, reaction times), we analysed mean driving speed and speed variability.\(^\text{15, 29−31}\) Interestingly, for all participants, the mean driving speed was slower, and the speed variability was higher in the updating task than in the flexibility task (condition with alternation). This result suggests poorer driving abilities in the updating task.\(^\text{15}\) This task would appear, therefore, to have a greater impact on driving performances. In the flexibility task, speed variability in both groups decreased significantly in the condition with

### Table 4

Comparison of Parkinson’s disease patients and controls on mean speed and speed variability in updating and flexibility tasks

<table>
<thead>
<tr>
<th></th>
<th>Parkinson’s disease patients, n = 25, mean (SD)</th>
<th>Controls, n =25, mean (SD)</th>
<th>One-tailed p-value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Updating task</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean speed (km/h)</td>
<td>83.3 (9.7)</td>
<td>82.4 (6.2)</td>
<td>0.365</td>
</tr>
<tr>
<td>Speed variability</td>
<td>8.6 (2.7)</td>
<td>10.1 (2.6)</td>
<td>0.022</td>
</tr>
<tr>
<td>Flexibility task †</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Condition without alternation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean speed (km/h)</td>
<td>94.6 (11.1)</td>
<td>90.6 (6.2)</td>
<td>0.099</td>
</tr>
<tr>
<td>Speed variability</td>
<td>7.9 (5.8)</td>
<td>6.9 (3.3)</td>
<td>0.453</td>
</tr>
<tr>
<td>Condition with alternation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean speed (km/h)</td>
<td>96.5 (15.5)</td>
<td>91.0 (6.3)</td>
<td>0.088</td>
</tr>
<tr>
<td>Speed variability</td>
<td>4.7 (2.4)</td>
<td>4.4 (2.3)</td>
<td>0.341</td>
</tr>
</tbody>
</table>

Values in bold are significant.

*Student t test or Mann−Whitney U test. One-tailed analyses were applied in accordance with our hypothesis: we expected patients with Parkinson’s disease to be significantly impaired compared with controls. Two-tailed analyses did not alter our main findings (data not shown).

†Two patients were excluded from the analysis because their data could not be analysed.
Observing adjustments in driving behaviour, especially in drivers who provide valuable data for predicting driving performances and for professionals. Our work could be tested in future research in order to examine the impact of the updating function in drivers with PD in real driving situations. In addition, these findings may have important clinical implications which ought to be taken into consideration by health professionals. Our work confirms that the TMT is a relevant neuropsychological assessment tool for clinicians in the evaluation of PD drivers. Moreover, the use of driving simulators could provide valuable data for predicting driving performances and for observing adjustments in driving behaviour, especially in drivers with mild to moderate PD.

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Competing interests

None.

Patient consent

Obtained.

Ethics approval

Ethics approval was provided by the Biomedical Ethics Committee, Lyon, France.

Provenance and peer review

Not commissioned; externally peer reviewed.

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Impaired updating ability in drivers with Parkinson's disease

Maud Ranchet, Laurence Paire-Ficout, Claude Marin-Lamellet, Bernard Laurent and Emmanuel Broussolle

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