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## Temporal Preparation Strategy may Inflate RT Deficit in Patients With Parkinson's Disease

Louis Bherer<sup>1</sup>, Sylvie Belleville<sup>2,3</sup>, and Brigitte Gilbert<sup>2</sup>

<sup>1</sup>Beckman Institute for Advanced Science and Technology, University of Illinois at Urbana-Champaign, Urbana, IL, USA, and <sup>2</sup>Institut Universitaire de Gériatrie de Montréal, Montréal, Qué., Canada, and

<sup>3</sup>Department of Psychology, Université de Montréal, Montréal, Qué., Canada

### ABSTRACT

Twelve patients with Parkinson's disease (PD) and 12 age-matched controls completed a visual reaction time (RT) task to assess the effect of temporal parameters on response preparation. Simple and choice RT conditions were presented in separate blocks. In both conditions, preparatory intervals of various durations (1, 3 and 5 s) were introduced between an auditory warning signal and the visual target. Within a block of trials, intervals varied randomly. The results indicated that PD patients responded slower than controls in both task conditions. Also, there was evidence for preparation in both groups, as RT decreased with increasing intervals. A three-way interaction indicated that PD patients' RT was longer than that of controls at the shortest interval in simple RT. This suggests that PD patients show a different pattern of temporal response preparation and that this may contribute to their deficit on RT tasks.

Parkinson's disease (PD) is characterized by slowness in movement initiation (akinesia), tremors and reduced movement execution. These symptoms have been associated with a degeneration of neurons that produce dopamine in the substantia nigra, which in turn results in a reduction of dopamine in the striatum and the putamen (Jahanshahi & Frith, 1998). Reaction time (RT) paradigms have been used extensively with PD patients to assess psychomotor symptoms. The majority of studies have reported increased RTs in PD patients relative to control participants (see Gauntlett-Gilbert & Brown, 1998 for a review). It has been proposed that RT paradigms might help to illuminate the putative relation between the cognitive impairments and deficits in the control of voluntary actions in PD (Berry, Nicolson, Foster, Behrmann, & Sagar, 1999). The present study addresses this issue by examining the ability of PD patients to use tem-

poral information to prepare a simple forthcoming response in reaction time tasks. Preparatory processes refer to the ability to develop and maintain an optimal processing state prior to the execution of movements. Preparing a response involves activating the appropriate action schemas in advance and maintaining their activation until the stimulus occurrence (Stuss, Shallice, Alexander, & Picton, 1995).

It has long been recognized that response preparation has a major impact on performance in RT tasks (Niemi & Näätänen, 1981). One way in which preparatory effects manifest themselves is through comparison of performance in appropriately matched simple and choice RT tasks. Choice RT involves a larger number of processes because it requires, in addition to stimulus detection and response execution, stimulus discrimination, response selection and in most cases, maintaining in memory the target and response

alternatives. Furthermore, in simple RT tasks, participants know in advance the exact response that they will have to produce and thus specific preparation can also occur. Thus, specific preparation partially accounts for faster RTs in simple than choice RTs.

A number of empirical findings comparing simple and choice RTs suggest that preparatory deficits exist in PD. The major empirical argument for this hypothesis is the presence in PD patients of a larger deficit in simple than Choice RT (Bloxham, Mindel, & Frith, 1984; Evarts, Teräväinen, & Calne, 1981; Goodrich, Henderson, & Kennard, 1989; Sheridan, Flower, & Hurrell, 1987). A failure to implement specific preparation of the response required in the simple RT task may account for the smaller advantage for simple over choice RT in PD patients relative to control participants. This failure to engage in specific preparation has been proposed to arise from impairment in the attentional control processes mediated by the frontal lobe (Gaunlett-Gilbert & Brown, 1998; Goodrich et al., 1989). This is in line with Fuster's view (Fuster, 1999) that the prefrontal cortex comes into play to organize and plan the temporal structure of actions.

However, some studies have not reported clear evidence of specific preparation impairment in PD based on the comparison of simple and choice RTs. In these studies, persons with PD are found to be slower in choice than simple RT tasks relative to control participants (Cooper, Sagar, Tidswell, & Jordan, 1994; Jahanshahi, Brown, & Marsden, 1992a). There are at least two major factors that could lead to a larger RT impairment in choice than in simple RT.

One is related to the fact that choice RT is more complex than simple RT, as mentioned earlier. The greater complexity of the choice RT task relative to the simple RT task may be particularly critical for PD patients who exhibit frontal impairments (Pate & Margolin, 1994), which is often the case (Gotham, Brown, & Marsden, 1988). However, this interpretation cannot easily account for the afore mentioned findings of a larger impairment in simple relative to choice RT found in a fairly large number of studies and for the finding of a reduced effect of a secondary task

in simple than choice RT in PD patients (Goodrich et al., 1989).

Another important source of discrepancy might be the absence of consideration of time parameters in the majority of studies comparing simple and choice RTs in PD. This point is important because the magnitude of the preparatory effect in RT tasks depends on both specific and nonspecific preparation. Specific preparation occurs when a predetermined response is associated with a specific stimulus, as in simple RT. Nonspecific or temporal preparation refers to the synchronization of an action in time and is based on signal expectancy and time uncertainty. Contrary to specific preparation, temporal preparation has a major impact in both simple and choice RT. Importantly, nonspecific preparation is dependent upon the temporal characteristics of the design.

The preparatory interval (PI), which is the interval between the warning signal and the target, is a determinant factor of temporal preparation (Niemi & Näätänen, 1981; Bertelson, 1967). When PIs vary unexpectedly across trials, stimulus likelihood increases with time and temporal preparation involves both temporal and probability information. For instance, if PIs of 1, 2 and 3 s occur randomly in a block of trials, the probability that the signal will occur after 1 s is  $1/3$ , then it increases to  $1/2$  at 2 s and it is perfect at 3 s. Because subjects prepare their response in line with the increased probability of occurrence of the target, RT typically decreases as the PI increases (Näätänen & Merisalo, 1977; Polzella, Ramsey, & Bower, 1989). For this effect to be observed, PIs need to be distinct (not too close in time) and embedded in a temporal window that can be used effectively by participants. The variable PI design is interesting because it is similar to the conditions of preparation that participants have to face in their daily lives, where actions are performed in a changing environment in which event occurrence is rarely perfectly predictable. Unfortunately, previous studies with PD patients have used PIs that do not yield optimal preparation in control participants and this could account for absence of group differences.

Studies that have shown an advantage of simple over choice RT in PD or a larger deficit in PD in choice RT, suggesting normal preparation, have

sometimes used short PI delays embedded in a very short time window (e.g., 0–250–500–2500 ms in Jahanshahi et al., 1992a). These are conditions that don't promote optimal preparation in control participants and that are thus less likely to yield group differences with PD patients. In contrast, studies that showed the smallest advantage of simple over choice RT in PD, supporting a specific preparation deficit, typically used long and distinct PIs over a large time range (e.g., 1500 and 2500 ms in Sheridan et al., 1987; 1500 and 3000 ms in Goodrich et al., 1989; 1800 and 2500 ms in Evarts et al., 1981). Using temporally distinct PIs may have facilitated the use of temporal parameters to enhance specific preparation in control participants, thus facilitating emergence of group differences.

PD patients exhibit larger RT deficits as a function of response (Brown, Jahanshahi, & Marsden, 1993) or stimulus uncertainty (Cooper et al., 1994). It is of major interest to investigate whether these patients will show a specific preparation deficit in task conditions that involve both temporal and probability information, such as with variable PI intervals. Analyzing the pattern of performance across PI values in a variable PI design will allow for an assessment of participant's ability to use temporal and probability information to prepare a response. Unfortunately, in many studies that have shown a preparatory deficit in PD patients, RT was pooled over PI values and the PI effect was not assessed (Evarts et al., 1981; Goodrich et al., 1989; Sheridan et al., 1987).

The goal of the present study was to understand more clearly the relation between temporal and specific preparation in PD patients using parameters that were most likely to yield temporal preparation in typical participants (Bherer & Belleville, 2002). The experiment compared choice and simple RT conditions in a variable PI design with three relatively long and well-defined PIs (1, 3 and 5 s). It was expected that analyzing the pattern of performance across PI values might provide informative data regarding PD patients' capacity to modulate their level of specific (simple RT) and nonspecific (choice RT) preparation. The impact of temporal parameters on the response process was assessed separately for the

cognitive and motor portion of the global RT. This was done by measuring response time from the release of a home key. This technique, also used by Jahanshahi et al. (1992a) with PD patients, is of particular interest with a clinical population suffering from slowness in movement execution. It was expected that the impact of preparation would specifically affect the pre-execution stages of response processing or the time taken to release the home key but not the execution time or the time to reach the response key (Bherer & Belleville, 2002; Jahanshahi et al., 1992a). Finally, the impact of attentional control and maintenance deficits on the response preparation of PD patients was explored by assessing the relation between performance on span and executive tasks and response preparation.

## METHOD

### Participants

Participants were 12 patients who received a diagnosis of Parkinson's disease from a neurologist specializing in movement disorders and 12 healthy matched controls. All participants were Francophone Canadians living in the Montréal community. All but 1 participant were native Francophone speakers. All control participants were in good health and none of them had undergone surgery or suffered from psychiatric disorders in the few years prior to testing. They had no history of neurological disease and did not take any medications known to affect cognitive functions. None of the patients were institutionalized or had suffered from stroke, head injuries, psychiatric disorders or other neurological problems. Severity of the disease was measured by the Hoehn and Yahr scale (1967). Three patients were in Stage 1, 4 in Stage 2 and 5 in Stage 3. Akinesia was the predominant symptom for 5 PD patients whereas bradykinesia was predominant for 3 others. Four patients suffered from both types of symptoms. For many patients, activities of daily living were carried out slowly with assistance. A motor exam substantially revealed difficulty arising from a chair, stooped posture, postural instability and bradykinesia. As shown in Table 1, the mean duration of the disease was 8 years, with a standard deviation of 5 years. All patients were on stable anti-parkinsonian medication at the time of testing. Two of them were taking anticholinergic drugs and dopamine agonists, while the others were taking L-Dopa with or without additional medication.

Demographic characteristics and scores on clinical tests for both the PD and the control groups are shown

Table 1. Groups' Mean for Demographic Characteristics and Test Scores.

Groups	<i>N</i>	Age	Years of education	Mattis	MMSE	GDS	Disease duration
PD	12	65 (11) [47–76]	12 (5) [5–19]	139 (4) [132–144]	29 (1) [27–30]	8 (5) [2–17]	8 (5) [3–19]
Controls	12	64 (10) [46–74]	13 (3) [9–21]	140 (4) [134–144]	29 (1) [27–30]	4 (3) [1–11]	

Note. Standard deviation (*SD*) along with maximum and minimum [min.–max.] values are presented in brackets. No significant difference was observed between the groups.

in Table 1. To exclude persons with dementia, all participants completed a short mental examination (MMSE from Folstein, Folstein, & McHugh, 1975) and the Mattis Dementia Rating Scale (Mattis, 1976). As shown in Table 1, PD patients and controls performed within the normal range on these examinations. The mean MMSE score was 29 in both groups and, mean score for the Mattis Dementia Rating Scale was 139 and 140 respectively for PD and control participants. None of the participants showed clinical signs of depression (DSM-IV, 1994). Nevertheless, as depressive symptoms are often observed in PD patients, the Geriatric Depression Scale (GDS; Yesavage et al., 1982) was used as an objective measure of depressive symptoms. PD patients showed slightly more depressive symptoms than normal controls, a difference that did not reach significance.

## Materials and Procedure

### Reaction Time Tasks

The experiment was under the control of *Psyscope 1.0.1* (Cohen, MacWhinney, Flatt, & Provost, 1993), running on a MacIntosh PowerPC. Participants started the trials and gave their response on a three-button response box (*Psyscope ButtonBox*). This device allows for the measurement of response initiation and execution time to the nearest millisecond. The three buttons of different colours (left to right; red, yellow and green) were arranged linearly on a 17 cm by 13 cm panel separated by 3 cm. Participants completed simple and choice RT tasks in which each trial was initiated by pressing the central button of the response box after a warning signal (a 1000-Hz tone at 75–80 dB). Participants were required to hold down the button until the occurrence of the imperative signal, which was a black circle 4 in. in diameter.

In the simple RT condition, the black circle appeared in the centre of the screen and participants were asked to react to the imperative signal by quitting

the home key and pressing the right response key as quickly as possible. Half-way through the block, they were instructed to respond to the left button. In the choice RT condition, the black circle occurred randomly either to the right or left of the centre of the screen and participants were asked to react to the imperative signal by quitting the home key and pushing down the corresponding response key to the right or left of the home key. In both the simple and choice RT conditions, PIs were 1, 3 and 5 s in duration. The proportion of each PI value was equated in each block of trials. They were presented in random order. After 5 practice trials on each task, a first block of 30 trials was completed in simple RT and a first block of 60 trials was completed in choice RT. Both the simple and choice RT conditions were conducted twice within a single experimental session and thus the total number of completed trials was 60 in simple RT (20 at each PI) and 120 in choice RT (40 at each PI). The second blocks were separated from the first by a 30–40-min delay during which the participants completed other unrelated experimental tasks (see Gilbert, Belleville, Bherer, & Chouinard, submitted). An ANOVA involving Block (1 and 2), Condition (simple vs. choice) and PI indicated neither an effect of block on initiation time, nor any interaction with group. Thus, the data were pooled over the two blocks for subsequent analyses.

### Neuropsychological Measures

*Psychomotor and motor measures* The neuropsychological assessment involved assessment of motor and psychomotor abilities, short-term memory and executive functions. These data were presented and discussed elsewhere (see Gilbert, Belleville, Bherer, & Chouinard, submitted) and thus only the aspects of the neuropsychological investigation believed to be of particular importance for the present study will be discussed here. Of major concern for our purposes, the participants completed a psychomotor task (DSST from the Ottawa-Wechler Battery,

1953) and a motor task (Purdue Pegboard). In the DSST task, the participants were presented with a key on which each number from 1 to 9 is matched with a geometrical symbol. The key was printed on the bottom portion of a sheet of paper. On the upper portion, a series of numbers were presented alone and the participant's task was to write down the geometric symbol corresponding to each number. The participant's score is the total number of items completed in 90 s. The Purdue motor task (Purdue Research Foundation, 1948) required putting round pegs into a series of holes aligned vertically on a board. Participants' score consisted of the total number of pegs placed in 30 s with the left hand, the right hand and both hands (bilateral).

### *Short-Term Memory and Executive Functions*

All participants also completed a digit span, a word span and a visuo-spatial span task to assess short-term retention capacity. The digit span procedure was an adapted version of the digit forward subtask of the Wechsler Adult Intelligent Scale (WAIS), presented in detail in Belleville, Peretz, and Malenfant (1996). The participants recalled orally sequences of digits that were drawn randomly from 1 to 9. The digits were read aloud by the examiner. Four sequences of a given number of digits (starting with two numbers) were available. If participants correctly recalled the first two series, sequences of one item longer were administered. The span corresponded to the longest sequence recalled correctly on at least half of the trials. Moreover, as part of an alphabetical recall test (described below), participants also completed a word span task. Short-term memory capacity for words was assessed using a classical span measure. Again, the span was defined as the longest sequence recalled correctly on at least 2/4 of the trials of a given sequence length. The visuo-spatial span task is a modified computerized version of the Corsi span. An array of 16 white squares (18 mm × 18 mm) with a black border appeared on the computer screen. Stimuli were localized semirandomly and half of them were situated on each side of the screen. Square sequences of varying length (from 2 to 8 items) were constructed with stimuli randomly selected from the pool of 16 squares with the only restriction that no square could be used twice in a same trial. For each length, four different sequences were created. White squares darkened sequentially for 2 s before returning to their original appearance. The inter-stimulus interval was 250 ms. Participants' task was to point at squares in the same order as they were presented. The length of the sequence began with two squares and was increased by one item every two trials. However, if an error occurred on one of these two trials, participants were

given two additional trials. Testing ended when participants failed to correctly report at least two sequences of squares of a given length. The span was defined as the longest sequence correctly reported on 50% of the trials on a sequence length.

The alphabetical recall test is intended to measure a specific executive function, that is, the ability to manipulate information in working memory. The critical aspect of the alphabetical procedure consists of comparing two conditions of immediate word recall: a direct condition in which items are recalled in the same order as presented, and an alphabetical condition in which participants are asked to recall the words in alphabetical order (according to the first letter of the word). This task has been used by Belleville, Rouleau, and Caza (1998) to investigate working memory functioning in normal older adults. The words used for this task were monosyllabic. French words were selected to meet the criteria for frequency and imaginable substantives, and were unambiguous with respect to the print-to-sound correspondence of their first letter. Words in a sequence never began with the same letter and shared no phonological or semantic similarity. Sequence length was also controlled for, taking into account the manipulation requirement of the sequences of words in the alphabetical condition. The number of words to be recalled in each condition corresponded to the participant's word span as measured previously. Participants completed 20 different sequences (10 in the direct condition and 10 in the alphabetical condition). The proportion of correct items recalled was calculated. The following equation expresses the performance on alphabetic recall when short-term memory capacity is taken into account:  $\text{Direct recall} - \text{Alphabetic recall} / \text{Direct recall}$ . This measure is considered to reflect one's ability to manipulate information in working memory.

## RESULTS

Two dependent variables were considered: initiation time and execution time. Initiation time (IT) was measured as the time elapsing from the occurrence of the imperative stimulus to the moment when participants removed their finger from the home key. Execution time (ET) was the time taken to move from the home key to the response button. Response times were compiled for correct answers only, and anticipate responses (i.e., leaving the home key before the imperative signal) were rejected. Trials were not included in the analyses if IT was shorter than 100 ms, or if the global response time (IT+ET) was longer

than 3000 ms. A trial was also excluded if IT was two standard deviations above or below a participant's average RT performance. On average, this resulted in excluding 4.9% of the trials in simple RT and 4.3% in choice RT for the PD participants, and 6.3% and 6.5% in simple and choice RT respectively in the control group.

## Reaction Time Tasks

### Initiation Time

The results of both task conditions are shown for PD and control participants in Figure 1. It appears that in both groups and in both conditions, RT was quicker as PI increased. In addition, the PI effect in the simple RT condition was larger in PD patients than in the control participants.

An ANOVA was performed on these data with Group as a between subject factor and Condition (simple vs. choice), Direction (left or right button) and PI (1, 3, 5 s) as within subject factors. The results indicated that persons with PD were slower than the control participants,  $F(1, 22) = 14.6$ ,  $p < .001$ ,  $\eta^2 = 0.40$ , and that IT decreased with PI,  $F(2, 44) = 25.8$ ,  $p < .001$ ,  $\eta^2 = 0.54$ . Moreover, the IT was longer overall in choice than in simple RT,  $F(1, 22) = 59.7$ ,  $p < .001$ ,  $\eta^2 = 0.73$ . The results also indicated a significant Condition by Direction interaction,  $F(1, 22) = 5.1$ ,  $p < .05$ ,  $\eta^2 = 0.19$ . There was no significant RT difference with response direction in the simple or the choice

RT conditions. The interaction was rather due to a larger difference between simple and choice RTs when participants were responding to the left (Simple, 361; Choice, 430;  $p < .001$ ,  $\eta^2 = 0.74$ ) than when responses were given to the right (Simple, 368; Choice, 424;  $p < .001$ ,  $\eta^2 = 0.66$ ). Importantly, this effect did not interact with the Group factor.

The Group by Condition by PI interaction reached significance,  $F(2, 44) = 3.39$ ,  $p < .05$ ,  $\eta^2 = 0.13$ . To understand this interaction more fully, an ANOVA was performed separately on choice and simple RT. On the choice RT, PD patients were slower than controls overall,  $F(1, 22) = 13.7$ ,  $p < .001$ ,  $\eta^2 = 0.38$ , and IT significantly decreased with PI,  $F(2, 44) = 6.23$ ,  $p < .01$ ,  $\eta^2 = 0.22$ , from the first to the second PI. This effect was equivalent in both groups, since there was no Group by PI interaction. In the simple RT condition, participants with PD were also slower to respond than control participants,  $F(1, 22) = 13.1$ ,  $p < .01$ ,  $\eta^2 = 0.37$ , and IT also decreased with PI from the first to the second PI,  $F(2, 44) = 36.2$ ,  $p < .001$ ,  $\eta^2 = 0.62$ . However, a significant Group by PI interaction,  $F(2, 44) = 3.3$ ,  $p < .05$ ,  $\eta^2 = 0.13$ , indicated that the group difference varied with the PI. Although significant for all PIs, the group difference was larger on the first PI (1 s,  $p < .001$ ,  $\eta^2 = 0.41$ ; 3 s,  $p < .01$ ,  $\eta^2 = 0.30$ ; 5 s,  $p < .01$ ,  $\eta^2 = 0.33$ ). The mean group difference for each PI was 120, 84 and 94 ms, respectively, at 1, 3 and 5 s. Furthermore, there was a larger PI effect for persons with PD ( $p < .001$ ,  $\eta^2 = 0.58$ ) than controls ( $p < .001$ ,  $\eta^2 = 0.29$ ). The RT improvement in simple RT from the 1 s to the 3 s PI was 73 ms in the PD group and 37 ms in the control group.

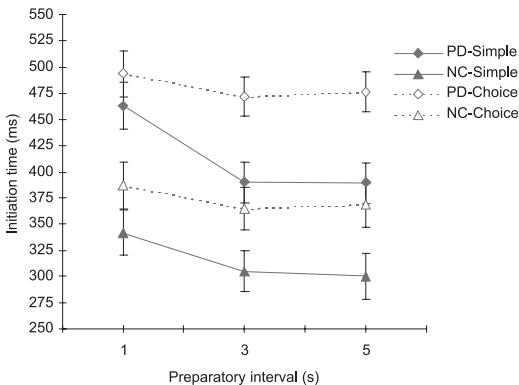


Fig. 1. Mean initiation time (ms) in simple and choice RT tasks as a function of preparatory intervals for PD (diamonds) and control (triangles) participants.

### Execution Time

An ANOVA with Group as a between subject factor and Condition (simple vs. choice), Direction (left or right button) and PI (1, 3, 5 s) as within subject factors was performed on the execution times. The findings indicated that participants with PD took longer to execute their responses than the control participants,  $F(1, 22) = 18.1$ ,  $p < .001$ ,  $\eta^2 = 0.45$ . The mean execution time was 353 ms in PD patients and 206 ms in control participants. Moreover, in both groups, execution time was

longer in the choice than the simple RT condition,  $F(1, 22) = 16.8$ ,  $p < .001$ ,  $\eta^2 = 0.43$ . The mean execution time was 324 ms in simple RT and 393 ms in choice RT in the PD group and 182 and 237 ms, respectively, in simple and choice RT in the control group. Importantly, no interaction with group was observed in execution time.

### *Error Rate*

In general, participants made very few anticipations and errors and many of them made no errors at all. The mean number of anticipations was, respectively for PD and control participants, 4 and 1.8 on the simple RT and 3.3 and 1.4 on the choice RT. The mean number of incorrect responses on the choice RT task was 0.1 and 0.2 for PD participants and controls, respectively. Due to the small number of errors and the frequent repetition of 0 scores among participants, non-parametric (Mann–Whitney) tests were used to assess group differences on global error scores. The results indicated that there was no significant difference between PD patients and control participants on anticipatory responses and incorrect responses.

## **Neuropsychological Measures**

### *Psychomotor and Motor Measures*

The mean number of items completed in the psychomotor test (DSST) was 39 in PD patients and 49.5 in the control group. In the motor test (Purdue Pegboard), the mean number of items completed was 14 in participants with PD and 23.8 in controls. These results suggest a reduced psychomotor and motor speed in PD patients, although the group difference was significant for motor speed only,  $t(22) = -6.5$ ,  $p < .001$ .

### *Short-Term Memory and Executive Functions*

The mean number of digits recalled correctly was 7 in both the PD and control groups. Short-term memory for words was also equivalent in both groups, with a score of 4.4 in PD and 4.8 in controls. The visuo-spatial measure was the only span measure to show a group difference,  $t(22) = -2.2$ ,  $p < .05$ , although this difference was rather weak (4.4 in PD and 5.3 in controls).

In the alphabetic recall procedure, the capacity to manipulate information in working memory is expressed by a performance score that reflects the reduction in recall incurred by the alphabetical condition (Direct recall – Alphabetic recall/Direct recall). Based on the number of items recalled, this score was 31% in PD patients and 16% in normal controls, which suggests that PD patients experienced greater difficulty recalling the words in alphabetic order,  $t(22) = 2.2$ ,  $p < .05$ .

### *RT Correlation With Motor and Cognitive Measures, Disease Duration and Severity*

Correlational analyses were performed to assess relations that might exist between performance on RT tasks and factors known to affect RT performance (e.g., chronological age, depression symptoms, motor symptoms). These results showed interesting findings that should be interpreted cautiously given the small sample of participants. Table 2 shows the results of these analyses. The results indicated that for PD patients, there was no significant relation between GDS score and performance on the simple or choice RT task. Age was highly but not significantly related to initiation time. Initiation time also shared a strong relation with performance on the psychomotor test (DSST) in both simple and choice RT, while execution time in these tasks was significantly related to the score on the motor test (Purdue Pegboard).

An important finding of the present study was that the PI had a larger impact on simple than choice RT performance in persons with PD (i.e., that PD patients do not prepare as much as controls for the shortest PI in simple relative to choice RT). To express this effect, a specific preparation score was derived to reflect the amount of preparation on the shortest PI for choice over simple RT (Choice–Simple at 1 s)–(Choice–Simple at 3 s). With this formula, lower scores represent lower preparation at the shortest delay. Not surprisingly, the PD (–49.8) group had a significantly lower preparation score than controls (–15.2),  $t(22) = -2.3$ ,  $p < .05$ . We tested whether this preparation score was related to executive abilities as measured by the manipulation score from the alphabetic recall procedure. Moreover, we also assessed whether the preparation deficit was related to the capacity to maintain information in short-term memory as

Table 2. Correlation Observed in PD Patients Between Performance on the RT Tasks (IT: Initiation Time, ET: Execution Time) and Age, Depressive Symptoms (GDS), Motor (Purdue) and Psychomotor Measures (DSST), and a Preparation Score.

	Age	GDS	Purdue	DSST	Alpha	W-span	D-span	VS-span	Dur	Severity
TRS-IT	.54	.15	-.39	-.55	.20	-.34	.05	-.21	-.27	-.01
TRS-ET	.56	.05	-.71**	-.35	.32	-.11	-.16	-.38	.38	.57*
TRC-IT	.54	.29	-.32	-.64*	.52	-.25	-.001	-.26	-.25	.06
TRC-ET	.32	-.04	-.63*	-.16	-.02	.15	-.06	-.14	.41	.58*
Preparation score	-.26	-.49	.004	.25	-.12	.59*	.65*	.59*	-.16	.34

Note. Alpha = Direct recall – Alphabetic/Direct recall, W-span = word span, D-span = digit span, VS = visuo-spatial span, Preparation score = (Choice–Simple at 1 s) – (Choice–Simple at 3 s), Dur = duration of the disease, Severity = stage on the Hoehn & Yahr scale.

\*Significant at the .05 level (2-tailed).

\*\*Significant at the .01 level (2-tailed).

measured by standard verbal and spatial span tasks, since Stuss et al. (1995) suggested that maintaining activation is an important aspect of preparation. As shown in Table 2, there was no relation between manipulation of information and preparation in PD patients. However, a significant relation was found between the preparation score and the ability to maintain information for a short time delay, as assessed by word span, digit span and visuo-spatial span. It is worth noting that the preparation score was unrelated to motor or cognitive speed, or to clinical measures. In control participants, the relation was nonsignificant between the preparation score and manipulation or span measures.

Finally, it can be argued that the pattern of RT slowing and/or the preparatory deficit observed are related to severity or duration of the disease. To explore these issues, correlations were computed between duration of the disease as measured by years and the severity of the symptoms according to the stage of the Hoehn & Yahr scale. The results (see Table 2) indicated that execution time (both in simple and choice RT) was significantly related to the Hoehn & Yahr scale, whereas initiation time and the preparation score did not correlate with this measure. Duration of the disease did not correlate with any of the RT or preparation measures.

## DISCUSSION

The findings reported in the present study indicate that both PD patients and control participants

enhance their performance with an increasing PI duration on simple and choice RT and that in both groups, the positive effect of PI is larger in simple RT than in choice RT. At first glance, the similarities in performance and the equivalent group difference observed in simple and choice RT do not readily support the hypothesis of a preparatory deficit in PD. However, preparation deficits are evident when considering the temporal parameters of the tasks. Indeed, it was observed that the RT decrease from the first to the second PI in the simple RT condition was larger in the PD group than in the control participants. This pattern of results was not obtained in the choice RT, in which the PI effect was equivalent in both groups. As a result, the magnitude of the simple over choice RT advantage was reduced in the shortest PI for PD participants. These results suggest that the deficit in the simple RT condition in PD patients is dependent upon temporal parameters. Notably, slowing was also observed in the choice RT condition. This is consistent with findings from previous studies (Cooper et al., 1994; Jahanshahi et al., 1992a) and could be due to impairment or slowing in stimulus identification and/or response selection processes. However, more importantly with regard to this study, the pattern of slowing in choice RT was independent of temporal factors. Taken together, these results bring support to the hypothesis that some aspect of preparing a specific voluntary action is impaired in PD and highlight the notion that temporal preparation interacts with specific

preparation to account for the preparatory deficit of PD patients.

Before turning to a discussion of the theoretical implications of our findings, it is necessary to address some methodological issues that may relate to our finding that the specific preparation deficit in PD participants is related to temporal parameters. First, in the present study, participants started the trial themselves. This was done to ensure that participants were fully attentive when the trial started with the PI occurrence. Moreover, only three PI values varying over several seconds were used. This method may have enhanced the use of temporal cues. Thus, it is likely that using three PIs that varied over several seconds favoured a large PI effect in the present study, which allowed for the isolation of an effect that was unexamined in previous studies.

It can be argued that medication may affect the capacity of persons with PD to use temporal information in preparing motor responses, since all of our patients were on anti-parkinsonism medication. However, this does not seem to be the case according to studies that have investigated this issue. Jahanshahi, Brown, and Marsden (1992b) found no impairment in the use of temporal cues after withdrawal from dopaminergic medication. Independence of drug treatment was also observed in Jordan, Sagar, and Cooper (1992), who compared treated and untreated PD patients on simple and choice RT and in Bloxham, Dick, and Moore's (1987) study, which investigated the detrimental effect of a dual task on simple RT. It might also be argued that the pattern of results reported in this study is related to the severity of the disease. Comparability of the patients is in fact of major importance when results from different RT studies are compared. However, our results indicated that there was no significant relation between severity or duration of the disease and the preparatory deficit, although the severity of the disease was correlated with motor slowness.

A number of explanations can be provided to account for the peculiar deficit of PD patients in the simple RT task, some of which can be ruled out by previous studies. First, PD patients may need more time to achieve a general alertness state. However, if this were true, preparation

deficits should have also occurred on choice RT. Furthermore, Jahanshahi et al. (1992a) found no evidence of a general arousal deficit in PD patients when measuring the efficacy of warning signals on RTs. Second, PD patients may have impairment in temporal processing of the whole temporal window in which PIs were embedded. However, this is unlikely. Both groups showed an equivalent PI effect in the choice condition, suggesting that preparation, as a function of increasing probability of signal, is a preserved aspect of preparation in PD patients. Moreover, there is no evidence in previous studies of a deficit in temporal preparation per se in PD patients (Jahanshahi et al., 1992a). Third, patients may be slower in preparing a specific response. It is indeed possible that persons with PD need a longer minimal time to prepare a specific response. Although we cannot completely rule out this explanation, there are two indications that lead us to some other explanations. First, previous studies have shown that PD patients do not take longer to benefit from a warning cue in simple RT, even when cues are presented only 1 s prior to the target (Bloxham et al., 1987; Jahanshahi et al., 1992a; Jordan et al., 1992; Rafal, Posner, Walker, & Friedrich, 1984). Second, there was no correlation between our preparation score and motor speed tasks.

A more satisfactory account of the preparatory deficit observed in PD in the simple RT task is that preparation of an action in a variable PI condition depends on the probability of occurrence of the target across time. In a variable PI condition, the subjective impression is that the shortest PI has the lowest probability of occurrence. It is thus possible that the larger group difference at the shortest PI comes from a different preparatory strategy in PD. Patients may prepare their response for the most probable events to the detriment of the least probable events. Other studies have shown a larger RT deficit with greater stimulus uncertainty in PD, using other RT paradigms (Brown et al., 1993; Cooper et al., 1994).

We argue that the strategy of favouring the most probable event arises from a difficulty maintaining the activation of a specific action schema for a large temporal window. When required to prepare

an action in a variable temporal context, persons with PD may favour the most probable moment because this prevents them from maintaining the activation of action schemas over long periods. This interpretation is compatible with findings of a correlation in PD between specific preparation (difference in simple and choice RT from the first to the second PI) and performance on three classical retention measures (word span, digit span and visuo-spatial span). This finding supports Stuss et al.'s (1995) proposal that preparing a response requires the activation and maintenance of the appropriate action schema. A reduction in maintaining capacity in PD could thus incur a preparatory deficit. Clearly, conclusions drawn solely on the correlations reported here should be interpreted cautiously given the small number of participants. Yet, the pattern of correlations is coherent with theoretical views on preparation. Such correlations can provide useful indications on the cognitive processes that need to be further investigated to better understand the relation between cognitive and motor action impairment in PD patients.

Finally, knowledge about deficits in response preparation could help understanding how cognitive impairments mediate motor slowness in PD (Henderson & Dittrich, 1998; Jahanshahi & Frith, 1998). Whereas motor impairments (bradykinesia) are the central symptoms of PD, cognitive slowing (bradyphrenia) and cognitive impairments also characterize these patients. However, the relation that might exist between these domains is still poorly understood (Jeannerod, 1997). Preparation is an optional, willful, attention-demanding ability that has a major impact on speeded motor response, and deficits or strategic changes in preparation account in part for the slowing of PD patients. The results of the present study suggest that when temporal preparation is taken into account, differences in preparatory strategy exist and may mediate RT slowness in PD.

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