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Both random and perseverative errors underlie WCST deficits in prefrontal patients

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Abstract

The specificity of the Wisconsin Card Sorting Test (WCST) as a marker of frontal lobe pathology remains controversial. One problem is the lack of a well established correspondence between WCST errors and specific cognitive or neural processes. The conventional scoring of non-perseverative WCST errors does not discriminate between errors related to the efficient test of hypotheses during set shifting ('efficient errors'), and random failures to maintain set ('random errors'). This inherent confusion in the non-perseverative error score probably minimizes the relative importance of random errors in frontal lobe pathology. In this study, we used a WCST version sensitive to differences between 'efficient' and random errors to examine set shifting deficits in patients with focal lesions to their lateral prefrontal cortex. As expected, patients showed abnormally high rates of perseverative errors. Interestingly, patients also showed enhanced rates of random errors suggesting constant shifts or fluctuations in their choice of sorting principle. These results suggest that more sensitive tests are needed to elucidate the association between a specific type of set shifting error and a particular type of frontal lobe pathology.

1. Introduction

The Wisconsin Card Sorting Test (WCST) is one of the most widely used tests of frontal lobe function in clinical and research contexts [15,22,24,32,33]. From its various scoring norms, perseverative errors are regarded as the main signs of frontal dysfunction. In addition, the number of achieved categories is often used as an equivalent indicator [13,15,21,24,32]. However, non-perseverative errors reduce the total amount of achieved categories, even though probably the brain mechanisms involved in this type of errors differ from those related to perseverative behaviour [3,11,14,29]. As a result, a category score of zero does not allow any valid interpretation in relation to a specific cognitive deficit or brain dysfunction, since failure to complete a category could reflect both an inability to shift set, as well as an inability to maintain set due to stimulus interference. This use of potentially unrelated WCST scores as exchangeable indicators of brain dysfunction probably weakens their cognitive interpretation and anatomical specificity [2,6,21,23,27].

There have been many recent attempts to achieve a better understanding of the cognitive nature of impairments in WCST performance, with the aim to obtain more valid test scores. This has often involved the use of WCST analogue versions to pinpoint distinct cognitive processes in card sorting. For instance, the California sorting test provides separate indexes for concept generation, concept identification and concept execution, as well as several measures of perseveration [10]. The Brixton test is sensitive to deficits in two separable rule-production factors related to strategy generation and strategy selection [7,30]. Other authors have used a WCST version to address errors specifically linked to deficits in attentional set-shifting ability rather than in concept formation or problem solving processes [26,29]. In this study we focus on the process of attentional set

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shifting in order to analyze more closely the nature of non-perseverative WCST errors.

A serious problem for the validity of any test scoring system results when the same score confounds both functional and dysfunctional processes. This seems to be the case with non-perseverative WCST errors as well as with any other scoring norms derived from them (i.e. Number of Categories Completed, Perceptual Level Responses). Using a modified WCST version, we have shown that normal subjects are forced to make non-perseverative errors early in the WCST series in order to find the new sorting rule [3,5]. This is a very efficient trial-and-error process in normal subjects, who can keep track of past incorrect rules to obtain quickly the new correct one. We have referred to this special class of non-perseverative errors as *efficient errors*, as they imply an efficient use of recent contextual information to optimize set shifting. It should be noted that an ideal subject would be expected to make efficient errors in half of the trials following a shift in the WCST rule. A different type of non-perseverative errors are those that involve a shift in set, but also an inefficient use of past contextual information. One example is when the sorting rule is missed continuously, or when there is only one isolated error in an otherwise clear series (i.e. a distraction error). We will refer to these failures to maintain set as *random errors* to differentiate them from efficient errors. Electrophysiological evidence from normal subjects has shown that random and efficient errors evoke distinct patterns of brain activation, and hence, it does not seem appropriate to consider them as equivalent phenomena [3].

Neurocognitive models of working memory provide a useful conceptual framework for interpreting WCST errors related to frontal dysfunction [8,9,15–20,25,28,29]. Working memory allows humans to move fluidly their mental set backward and forward in time so as to project the next action [17]. Fig. 1 illustrates three schematic examples of such a process when a subject faces the 2nd card of a new WCST series, i.e., after having been prompted to shift category by the first negative feedback. An ideal subject would hold recent information online and discard the now irrelevant category, selecting one of the two remaining categories. However, such an ideal subject would be expected to make efficient errors in half of all 2nd trials, and to select the correct category from the 3rd trial onwards (Fig. 1a). Any deviation from this ideal pattern might reflect a disruption in such set shifting operations involved in card sorting [14,26,29]. Fig. 1B illustrates an extreme example of perseverative behaviour, where a previously established set rigidly determines the response in the early trials of a new series despite disconfirming feedback (i.e., a "stuck-in-set" tendency; [22]).

Another type of WCST deficit has been described as the failure to maintain set. This deficit may be related to the susceptibility of patients with prefrontal lesions to distraction and interference, or to problems integrating temporally separated events [11,17,21]. Accordingly, this type of patients would be expected to experience difficulties in set maintenance given the alleged role of prefrontal cortex in maintaining information online in working memory [16,25,28]. Fig. 1c illustrates a possible model of how abnormally rapid degradation of online information from the previous trial (e.g., due to stimulus interference), could deteriorate performance on subsequent trials. In extreme cases, loss of online information would lead to a random selection of the next card. Therefore, the inherent confusion in the scoring of non-perseverative errors in the conventional WCST reduces its ability to discriminate between efficient non-perseverative errors (see Fig. 1a) and inefficient non-perseverative errors (see Fig. 1c). This may

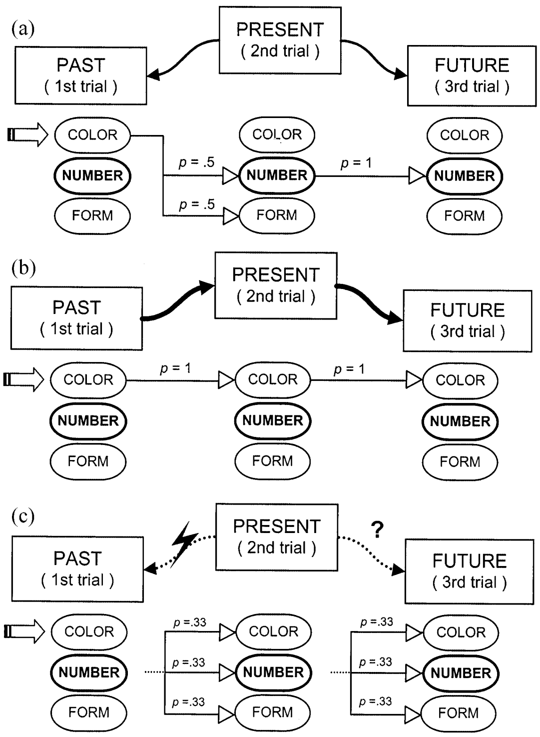

Fig. 1. 3 working memory models to account for WCST performance during 2nd shift trials. All examples illustrate a shift from Colour (wide arrow) to Number (in bold). Black arrows model working memory function. White arrows are estimates of the response probabilities predicted by each model. (a) An ideal subject would use past contextual information efficiently to discard the now irrelevant rule: one of the two remaining rules is chosen in the 2nd trial; only the correct rule is chosen from the 3rd trial onwards. Note that half of the 2nd trial choices will result in non-perseverative errors. (b) An extreme perseverative tendency (i.e. stuck-in-set) determines response selection early in a new series. (c) Interference from irrelevant stimulus dimensions lead to rapid loss or deterioration of information about recently sorted cards, which results in a random choice of category (see text for a full explanation).

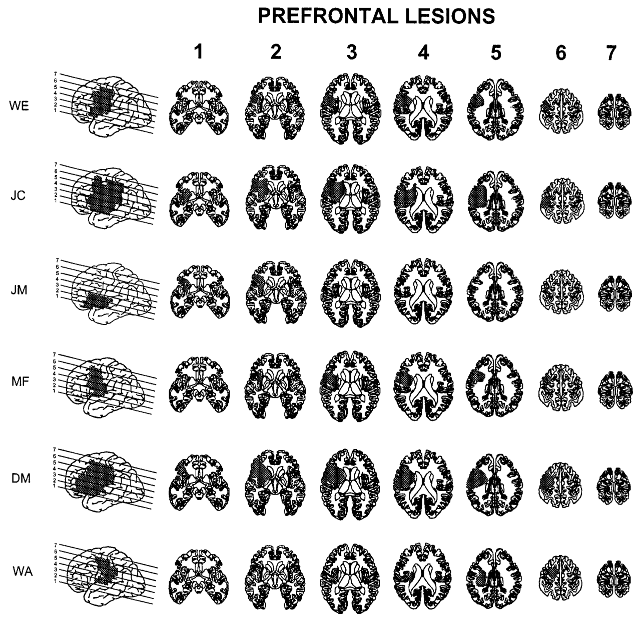

Fig. 2. Lesion reconstruction is shown for the 6 left dorsolateral prefrontal patients. Prefrontal damage was due to cerebral stroke in all cases. Lesions are transcribed onto axial templates using 5 mm cuts. Each row shows the extent of damage in an individual patient. All lesions overlapped over posterior portions of Brodmann areas 9 and 45. The average tissue loss was 41.4 cm^3 per patient. Software permitted reconstruction of the lateral perspective of the lesion, determination of lesion volume and putative cytoarchitectonic area damaged.

have led many authors to overlook the role of inefficient non-perseverative errors (i.e. random errors) as indicators of prefrontal lobe pathology.

In the present study we examined the relative incidence of perseverative and random errors, as segregated from efficient errors, in a sample of patients with focal lesions to their lateral prefrontal cortex. Our WCST version had been previously used to explore set shifting processes in normal subjects [3,5]. Our version emphasises the process of shifting set rather than other aspects tapped at by the conventional WCST such as problem solving [13,21,22]. It was expected that the differential analysis of non-perseverative errors into efficient and random errors would offer a more sensitive measure of card sorting ability in prefrontal patients.

2. Methods

Patient sample. 6 patients were selected on the basis of unilateral focal lesions to their lateral prefrontal cortex as determined by computed tomography (CT) or magnetic resonance imaging (MRI) scanning (Fig. 2). All lesions were caused by single stroke, and were restricted to the left frontal lobe. Maximal lesion overlap ($>67\%$ across patients) was centered in the posterior portion of Brodmann's areas 9 and 46, but damage extended inferiorly and posteriorly to areas 6, 8, 44, and 45. Testing took place at least one year after the injury. Medical complications, psychiatric disturbance, substance abuse, psychoactive drug treatment, or other neurological diseases were criteria for exclusion. All patients had normal or corrected to normal visual acuity. The average age of the patients was 62.8 ± 13.6 years (1 female; 5 male), and they did not show significant signs of intellectual impairment (WAIS-R Performance IQ scaled scores ranged from 95–135; median = 110). All 6 patients exhibited some degree of non-fluent aphasia, but comprehension was intact in all patients. 3 patients had upper motor neuron weakness in the limb contralateral to their lesion and used their ipsilesional limb to respond. This study was not concerned with the hemispheric localization of WCST deficits. Instead, our prime objective was to explore the relative incidence of perseverative and random errors in patients with restricted lateral prefrontal damage. In this respect, lesions to the left lateral prefrontal cortex have been shown to compromise set shifting ability [12,14,22,29].

Control sample. 8 healthy subjects were matched for age (mean age 66.3 ± 7.1 years; 2 female) and years of education (mean 13.1 ± 2.1 years) to the patients, and were free of neurological or psychiatric disease. Both patients and their age-matched controls were tested at the Martinez VA Medical Center. In addition, a group of 50 young subjects (mean age 23.0 ± 4.1 years; 24 female) were tested at the Complutense University (Spain) as part of a standardisation sample for the WCST adaptation. All participants gave written informed consent after a detailed explanation of the procedures were presented to them.

Stimuli and procedure. The computer version of the WCST used in this experiment was designed to assess attentional set shifting rather than other aspects of the conventional WCST like concept-formation or problem-solving. It has been previously used to explore electrophysiological activation related to set shifting in normal young subjects [3–5]. The task consisted of the 24 unambiguous cards of the WCST [24], that were repeatedly employed to produce a total of 18 series. The length of each series varied randomly between 6 and 9 trials, so that subjects could not predict the start of a new series. Inter-trial intervals varied randomly between 2 and 3 s. The average duration of the task was 20 min.

Each trial began with the onset of a compound stimulus including four WCST reference cards located on top of one response card centered in the middle of a computer monitor. The compound stimulus subtended a visual angle of 4° horizontally and 3.5° vertically at a distance of 1.5 metres. Subjects were instructed to match the response card with one of the four reference cards following one of the three possible rules: number, colour, or shape. Thus, subjects were informed about the three classification rules, and that the correct rule would change without notice. Subjects were requested to find the new rule as rapidly as possible. The correct rule was determined on the basis of auditory feedback delivered 1.6 s after the response through a computer-generated tone (300 ms in duration; 75 dB SPL; 2000 Hz for correct, 500 Hz for incorrect). Subjects used a response panel with four buttons. The far left button designated the reference card on the far left of the display, the far right button designated the card on the far right, and so on. Subjects used both thumbs for responding, except for 3 patients with motor weakness who used the hand ipsilateral to their lesion.

Subjects were allowed to practice the task until they were confident they had understood the instructions. This took less than 10 min for both controls and patients. The sequence of trials used for practice was different from that in the main task. After practice, subjects received no further help with the main task. The task was administered twice in separate sessions several days apart to complete 36 series in total.

Scoring of errors. Our scoring method of WCST errors benefited from recent electrophysiological evidence suggesting that different neural processes are engaged during shift and non-shift trials in the WCST series. Normal subjects are in the process of shifting set during the 2nd or 3rd trials of a WCST series, whereas late trials in the series consist of non-shift trials [3–5]. Therefore, errors committed in the 2nd and 3rd trials of each WCST series were scored as 'Early errors'. Errors in the last two trials of each WCST series were scored as 'Late errors'. Real examples of this scoring system are given in Table 1.

Table 1
Case illustrations of the scoring system of the WCST adaptation

Category shift in force (series No, patient's initials)	Patient's responses in the current series and in two previous trials (*errors are in italics*)									
Efficient shifts										
	Previous	1°	2°	3°	4°	5°	6°	7°	8°	9°
Color to number	C,C	C	F	N	N	N	N	N	N	
(7, DM)	*c,c*	*1w*	*ef*	*c*				*c*	*c*	
Number to form	N,N	N	F	F	F	F	F	F		
(12, JM)	*c,c*	*1w*	*c*	*c*			*c*	*c*		
Number to color	N,N	N	C	C	C	C	C	C		
(6, JM)	*c,c*	*1w*	*c*	*c*			*c*	*c*		
Random shifts										
	Previous	1°	2°	3°	4°	5°	6°	7°	8°	9°
Number to color	N,F	N	N	C	N	N	N	F	C	F
(2, MF)	*c,r*	*1w*	*p*	*R*					*r*	*c*
Form to color	F,F	N	C	F	N	F	N	N		
(13, WA)	*c,c*	*1w*	*c*	*R*			*r*	*p*		
Color to form	C,C	C	F	C	N	C	F	F	F	
(4, JM)	*c,c*	*1w*	*c*	*R*				*c*	*c*	
Perseverative shifts										
	Previous	1°	2°	3°	4°	5°	6°	7°	8°	9°
Number to color	C,N	N	N	C	N	N	N	N		
(8, JC)	*r,c*	*1w*	*p*	*c*			*p*	*p*		
Form to color	N,F	F	F	F	N	N	N	N		
(16, WE)	*r,c*	*1w*	*p*	*p*			*p*	*p*		
Number to color	N,N	N	C	C	C	F	F	F		
(8, MF)	*c,c*	*1w*	*c*	*c*			*p*	*p*		
Color to number	C,F	C	C	C	N	C	F	C	F	C
(7, WA)	*c,r*	*1w*	*p*	*p*					*r*	*r*
Stuck-in-set										
	Previous	1°	2°	3°	4°	5°	6°	7°	8°	9°
Number to color	N,N	N	N	N	N	N	N	N		
(6, JC)	*c,c*	*1w*	*p*	*p*			*p*	*p*		
Anticipations										
	Previous	1°	2°	3°	4°	5°	6°	7°	8°	9°
Color to number	N,C	N	C	N	C	N	C	C		
(11, WA)	*r,c*	*c*	*r*	*c*			*r*	*p*		

Note. C: Color sort; N: Number sort; F: Form sort; *c*: correct response; *1w*: first warning error; *ef*: efficient error; *r*:random error; *p*: perseverative error.

Table 2
Number of early errors predicted by each of the models in Fig. 1

	Early errors		
	Efficient	Perseverative	Random
Fig. 1A 'Ideal subject'	18	0	0
Fig. 1B 'Stuck-in-set'	0	48	0
Fig. 1C 'Random sorts'	0	24	24

Note: estimates are computed out of 36 series of the WCST adaptation.

WCST errors were scored as a function of past contextual information. An '*efficient error*' was defined as a shift to the wrong category in the 2nd trial of an otherwise clear series (i.e., series with no further errors other than the first warning error). Efficient errors were scored only in the 2nd trial of the series, and were incompatible with any other error in the remaining trials of that series. A '*perseverative error*' was defined as a failure to shift category after receiving negative feedback from the previous trial. A '*random error*' was defined as a shift to a wrong category different from the one chosen in the previous trial. Random errors were compatible with other errors earlier or later in that series. They indicate that the subject has not kept track of all previously discarded categories. Table 2 lists estimates of the expected number of different errors according to the models illustrated in Fig. 1.

Scoring of set shifting. Different patterns of early and late errors along each WCST series denote varying degrees of set shifting ability. We defined five of such patterns. First, an '*efficient shift*' was scored for those series where the subject hit the new correct category after prompted by the first negative feedback or after making one efficient error. An efficient shift score was incompatible with any other error in the series. In spite of this strict criterion, efficient shifts are the most common type of shifts in normal subjects [3–5]. Second, a '*random shift*' was scored given whenever there was a shift in category, but the subject also made at least one random error in the series [13]. Third, a '*perseverative shift*' was defined as a special class of random shift. They were scored whenever perseverative errors equalled or outnumbered random errors in that series. A perseverative shift score reflects a perseverative tendency compatible with a change in the sorting rule within that series. Fourth, a '*stuck-in-set*' score was given to those series consisting of just perseverative errors, and with no observed shifts in category. The 'stuck-in-set' score corresponds with the strong perseverative tendencies described in some prefrontal patients [22]. Finally, an '*anticipation*' score was given when the subject obtained the correct category in the first trial of the series. In our WCST version the sorting rule changed after a variable number of trials independently from the behaviour of the patient. This feature had the advantage to force a sufficient number of shifts for analysis, but could also lead to anticipatory correct responses when the new series was ruled by the perseverated-to principle [13]. Although anticipations are rare in normal subjects, they might amount to a third of all series in patients with strong perseverative tendencies. Case illustrations of all five types of WCST shifts and their associated types of errors are provided in Table 1.

Statistical analyses. Non-parametric Mann-Whitney tests were used for group comparisons of all behavioural indexes. Wilcoxon tests were used for within-subject comparisons (i.e., early versus late trial comparisons). Performance of the patient group was quite homogeneous as reflected in the standard error of the means shown in Table 3. A significance level of 0.05 was used for all contrasts.

3. Results

The group of 8 old control subjects closely replicated the expected pattern of WCST errors and the profile of

Table 3
Mean (and S.E.M) number of correct and error trials from the WCST adaptation in the group of left prefrontal patients, their age-matched controls, and a group of young adults

		Early trials Errors					Late trials Errors		
	Correct	Total	Efficient	Perseverative	Random	Correct	Total	Perseverative	Random
Patients	35.3[a]	36.7	1.3[a]	10.0[a]	25.3[a]	40.9[a]	31.0[a]	12.5[a]	18.5[a]
($N=6$)	(4.1)	(4.4)	(1.3)	(2.1)	(4.4)	(3.0)	(2.8)	(1.6)	(2.8)
Old adults	48.5	23.5	13.8	0.6	9.1[b]	70.1	2.5	0.6	1.9
($N=8$)	(2.1)	(2.1)	(1.1)	(0.3)	(1.9)	(1.2)	(1.2)	(0.3)	(1.2)
Young adults	51.1	20.9	15.4	1.2	4.5	70.0	2.0	0.5	1.4
($N=50$)	(0.7)	(0.7)	(0.5)	(0.2)	(0.4)	(0.3)	(0.3)	(0.1)	(0.2)

Note: Scores were computed from a total of 72 responses across early and late trials.
[a] Significant differences between prefrontal patients and old controls at $P<0.01$.
[b] Significant differences between old and young adults at $P<0.05$.

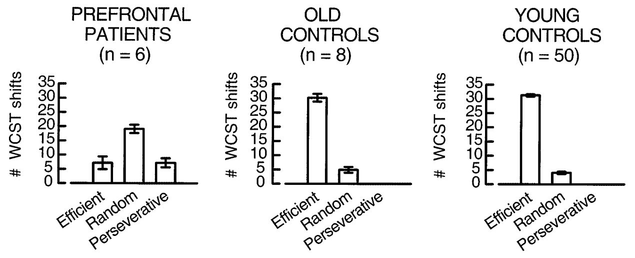

Fig. 3. Mean number of efficient, random and perseverative WCST shifts scored by the patients, their age-matched controls and the group of young controls. Vertical bars represent standard errors of the mean.

set shifts observed in previous studies [3–5]. Old controls committed mostly efficient errors in the early trials of the WCST series, a lesser amount of random errors, and very few perseverative errors. Table 3 shows that error scores for the old controls were similar to those of the sample of 50 young subjects. The only difference between age groups was a larger number of early random errors in old controls than in young controls (Mann Whitney U test, $Z = -2.5$; $P < 0.02$).

In marked contrast, prefrontal patients made significantly more total errors than their age-matched controls both during early (Mann Whitney U test, $Z = -2.3$; $P < 0.05$) and late WCST trials ($Z = -3.1$; $P < 0.002$; see Table 3). In early trials, these differences reflected significantly less efficient errors ($Z = -3.2$; $P < 0.001$), more perseverative errors ($Z = -3.2$; $P < 0.001$) and more random errors ($Z = -2.7$; $P < 0.01$) than the old controls. A similar pattern was observed for errors in late trials (Table 3). These group differences disappeared when efficient and random errors were combined together as non-perseverative errors ($Z = -0.9$, $P = 0.4$). All subjects were more prone to making random errors early than late in the WCST series. This was true both for the patients (Wilcoxon test, $Z = -2.3$, $P < 0.04$), the old controls ($Z = -2.5$, $P < 0.02$), and the young controls ($Z = -5.3$, $P < 0.001$). In turn, none of the groups showed significant changes in the perseverative error score from early to late WCST trials ($Z = -1.36$, $P = 0.172$, for patients) (see Table 3).

Prefrontal patients had an abnormal profile of WCST shifts compared to that of old controls. Fig. 3 shows that prefrontal patients accomplished significantly less efficient shifts (Mann Whitney U test, $Z = -3.1$; $P < 0.002$), more random shifts ($Z = -3.1$; $P < 0.002$), and more perseverative shifts ($Z = -3.4$; $P < 0.001$), than old controls. However, the groups did not differ in their mean number of stuck-in-set series (0.7 ± 1.2 S.D. for patients, 0.0 ± 0.0 S.D. for old controls; $P = 0.1$), nor in their mean number of anticipations (1.9 ± 1.6 S.D. for patients, 0.6 ± 0.9 S.D. for old controls; $P = 0.2$).

4. Discussion

The present results clarify the confusion inherent to the scoring of non-perseverative errors in the conventional WCST. The scoring norms of our WCST version showed remarkable consistency across age groups of normal subjects, and were sensitive to deficits in card sorting in prefrontal patients. Impaired WCST performance in prefrontal patients was caused by a larger number of perseverative errors, but also by significantly more random errors. As with the conventional WCST, successful performance of our WCST version demanded that subjects (a) efficiently changed the sorting rule on the basis of previous feedback, and (b) kept the rule in mind through varying stimulus conditions while ignoring irrelevant aspects of stimulation [13]. Changes in the structure of the series and in the scoring of errors were made to avoid ambiguous responses and to segregate efficient from random errors.

Normal subjects performed consistently even despite considerable differences in age and cultural background. A number of features of this normal pattern of performance are worth noting. Most errors in normal subjects were efficient errors (53.0% in old controls, 67.2% in young controls), with a lesser amount of random errors (35.0% in old controls, 19.7% in young controls). In both groups, the number of random errors declined significantly from early to late trials. This is consistent with the behavioural improvement that accompany post-shift costs in response accuracy [1,14,29]. This improvement in task-set accuracy is in agreement with physiological evidence that different brain mechanisms are in play during shift and non-shift WCST trials [4,5,19]. In turn, perseverative errors represented a minority of all errors (4.6% in old controls; 7.4% in young controls), and their incidence did not vary from early to late trials in the series. Normal age groups only differed in the number of early random errors, which suggests that this index is sensitive to age differences in attentional set shifting ability (see Table 1).

This new scoring system was sensitive to card sorting deficits in the group of prefrontal patients. Significant differences between patients and age-matched controls were apparent in almost all indexes, with the exception of the number of stuck-in-set series and anticipations. In line with previous reports, prefrontal patients made more perseverative errors than their age-matched controls [21,22,24,26], but they also made a larger number of random errors (Table 3). The relative simplicity of the task for normal subjects greatly reduced standard errors of measurement, and hence, improved the sensitivity of our measures to even minor deviations from normality. This confirms the view that, devoid of its problem-solving dimension, most normal subjects are unlikely to fail the WCST [15,21]. These results also suggest that prefrontal lesions impair the processes underlying attentional set shifting in the WCST [14,29], independently from the concept-formation or problem-solving aspects also involved with the conventional test. This observation was first made explicit by Milner in her seminal work [22].

The tendency of some prefrontal patients to sort apparently at random may have gone undetected due to the inherent confound in the scoring of non-perseverative errors, and the extended use of the number of categories completed as a summary score for WCST performance. The absence of differences in non-perseverative errors between clinical and normal groups may have motivated prior explanations that any deficit in the category score be attributed to perseverative errors alone. Indeed, authors often interpret a low category score in the conventional WCST as indication of a failure to shift set due to strong perseverative tendencies [15,22]. The present results suggest that this may not be always the case with prefrontal patients. In fact, extreme perseverative tendencies leading to a 'stuck-in-set' score were rare and amounted to only 5% of all series. More often patients simply lost track of the ongoing category, and in 52% of the series patients produced more random errors than perseverative errors (Fig. 3).

Computational models of prefrontal function regard non-perseverative errors as one important deficit of prefrontal patients together with the perseverative response tendencies. In general, the cognitive deficits postulated to underlie non-perseverative errors seem related to the strength and management of representations in working memory [15]. For instance, disruptions in cognitive components like episodic memory and reasoning [8], strategy selection [7,12,30], learned irrelevance [26,34], inhibition, task management and monitoring [31], might all account for non-perseverative errors. It has been proposed that cognitive deficits in prefrontal patients are due to a mixture between two apparently opposing trends: prefrontal lesions can lead to increased perseveration if there are changes in reinforcement contingencies, but to decreased perseveration if there are changes in the stimuli presented. This has been referred to as the "novelty-perseveration paradox" [20]. Under certain circumstances, this paradox may account for an increase in non-perseverative errors in frontal patients with no relative increase in perseverations [34].

However, the prediction that perseverations should predominate over other types of WCST errors continues to add confusion to the interpretation of results from some models when these are based exclusively on WCST data. In their computer simulation, Kimberg and Farah [16] obtained a result compatible with our random sorts mode in Fig. 1c (see Table 2), with similar rates of non-perseverative errors in prefrontal patients and controls. However, they interpreted this outcome as an imperfection in their model. Moreover, their simulation did not include the fact that normal subjects need to make errors during the efficient testing of hypothesis. Other WCST models present functional analyses of perseverative errors, but suggest that assessing the processes behind non-perseverative errors "requires more sensitive tests" [8].

Do prefrontal patients show a deficit in attentional set shifting? There are reasons to attribute the present group differences to deficits in the operations underlying attentional set shifting. In spite of the signs of non-fluent aphasia shown by all 6 patients, they were able to sort the cards correctly on command. We assured that task instructions had been understood during practice trials, and this was confirmed when patients were debriefed at the end of the task. As with old and young controls, patients did establish set along each series, as suggested by their significantly lower number of errors in the late trials of each series (Table 3). Most patients described their problems sorting cards by saying that they were 'confused' or 'baffled' by the cards. One patient (WE) used to repeat aloud to himself the 3 categories when attempting a new shift in category. It appeared as if he had problems in keeping online all the information needed to shift category. As a result of these difficulties, patients took an average of 2.6 s longer than controls to sort each card. This is consistent with the delayed latencies observed in prefrontal patients engaged in task-set shifting tasks [12,14,29]. Whether random errors in the WCST or other frontal tasks reflect disruptions in the generation and selection of rules [7,30], interference from prior sets [1], failure to engage a previously irrelevant category [26,34], deficits in the speed to reconfigure set [14], or difficulties in filtering out distracting stimulus features present in the cards [12], will have to be addressed more closely by future studies.

Without minimizing the importance of perseverative errors, the present results suggest that random errors contribute to the set shifting deficits of prefrontal patients. For the most part, our patients showed difficulties maintaining their attention focused on the newly relevant category in the presence of distracting stimulus features. The focal nature of the lesions, the homogeneous performance as a group, and the large number of category shifts assessed confer the present data with sufficient inferential power. Future research should explore further the association of different patterns of set shifting errors with lesions in various prefrontal regions (i.e. the "perseveration — distraction paradox"; [3,20]. The proposed segregation of random errors from efficient errors, as well as that of set shifting from problem-solving processes, clarifies the inconsistencies reported in the recent WCST literature [2,23,27].

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