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Recency Discrimination Deficits in Frontal Lobe Patients

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Damage to the frontal lobes appears to cause a deficit in the temporal organization of memory. M. P. McAndrews and B. Milner (1991) found that subject-performed tasks (SPTs), which involve the performance of actions with common objects, allowed frontal-lobe-damaged patients to circumvent this deficit and perform normally on recency judgments. The present investigation of the critical properties of SPTs compared the performance of frontal-lobe-damaged patients and healthy controls on recency judgments under 5 encoding conditions: SPT, naming, visual imagery, experimenter-performed tasks, and verbal elaboration. Patients' performance varied across encoding conditions, but controls' did not. Post hoc comparisons confirmed that patients performed significantly worse than controls across all encoding tasks except SPT. The findings help elucidate the nature of both SPTs and memory for temporal order.

The relationship between memory and the frontal lobes is complex. Although damage to the prefrontal cortex apparently does not cause a memory deficit, it can lead to a variety of other cognitive impairments that, in turn, can affect mnemonic functioning. For example, patients with frontal lobe damage appear to have difficulty with sequential behavior. As a consequence, memory may be impaired because of a deficit in the ability to temporally order recalled events. Milner and her colleagues demonstrated that damage to the frontal lobes appears to result in a deficit in the temporal organization of memory (Milner, 1971, 1982; Milner, Corsi, & Leonard, 1991; Milner & Petrides, 1984; for a review, see Schacter, 1987).

Impairment of memory for temporal order disproportionate to the severity of their event memory deficits has been observed in various patient populations. Most of these patients have either frontal lobe damage (Ladavas, Umilta, & Provinciali, 1979; Lewinsohn, Zieler, Libet, Eyeberg, & Nielson, 1972; Milner et al., 1991; Shimamura, Janowsky, & Squire, 1990) or lesions in areas heavily connected to the frontal lobes. For example, temporal order memory has been studied in patients with Korsakoff's syndrome (Huppert & Piercy, 1976; Meudell, Mayes, Ostergaard, & Pickering, 1985; Shimamura et al., 1990; Squire, 1982), patients with heterogenous amnesic disorders (Hirst & Volpe, 1982), detoxified chronic alcoholic patients (Salmon, Butters, & Shuckit, 1986), closed-head-injury patients (Vakil, Blachstein, & Hoofien, 1991), schizophrenic patients (Schwartz, Deutsch, Cohen, Warden, & Deutsch, 1991), and Parkinson's disease patients (Sagar, Cohen, Sullivan, Corkin, & Growdon, 1988; Sagar, Sullivan, Gabrieli, Corkin, & Growdon, 1988; Sullivan & Sagar, 1989; Vriezen & Moscovitch, 1990). Furthermore, a number of investigators have demonstrated that lesions in analogous areas in rodents (Kesner & Holbrook, 1987) and primates (Pribram & Tubbs, 1967; Tubbs, 1969) result in a deficient memory for temporal order. With few exceptions (e.g., Bowers, Verfaellie, Valenstein, & Heilman, 1988; Kopelman, 1989), findings in the human and animal literature are consistent with the existence of a relationship between the frontal lobes and temporal organization of memory.

McAndrews and Milner (1991) examined the effect of encoding strategies on temporal order memory. They investigated whether a noneffortful, nonstrategic encoding technique would allow patients with frontal lobe damage to circumvent their temporal order memory deficit and perform normally on recency judgments. The encoding technique that these authors investigated, subject-performed tasks (SPTs), was developed by Cohen (1981). An SPT simply involves performing an appropriate action with a to-be-remembered object.

After giving a recency discrimination task to patients with unilateral frontal lobe damage and to normal control subjects, McAndrews and Milner (1991) compared the use of SPTs to a standard naming condition. Although patients with frontal lobe lesions were severely impaired on the

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recency discrimination task in the naming condition, their performance was equivalent to that of normal controls after performing actions with the objects. Using SPTs during encoding thus overcame a temporal ordering deficit for patients with frontal lobe lesions.

A number of factors may have been responsible for the SPT effect. Some particular aspect of SPTs, such as the activation and execution of motor programs, the movement-through-space feature, or their self-involved–referential nature, may have been critical. In addition, performing an action may have provided a stronger, that is, a more elaborative or distinctive, memory trace. In this latter case, other elaborative techniques would be expected to achieve a similar result.

To evaluate these alternative explanations, in the present study we used a design contrasting five different encoding conditions, three of which share specific salient features with SPT. The distinctive characteristics of enacting an SPT include elaboration, the activation and execution of motor programs, general movement through space, and self-involvement. In addition to SPTs, we used an experimenter-performed task (EPT) condition in which subjects observed the examiner perform tasks with the objects. This condition involved movement through space without the motor programming or self-involved aspects. We also used a visual imagery condition in which subjects imagined themselves performing various actions with the objects. This condition incorporated self-involvement and possibly the activation of motor programs without either the movement feature or the execution of motor programs. A verbal elaboration condition required that subjects provide estimates of how often they use the objects and the last time they used them. It encompassed the self-involved characteristic without requiring either movement or motor programs. All three of the above conditions provide elaborate encoding, similar to SPT. Finally, simple object naming was used as a control condition because it shares none of the salient features of SPT. In addition, naming allowed replication of McAndrews and Milner's (1991) findings. Taken together, these conditions permitted a number of possible dissociations, any of which would shed light on the salient features of SPTs.

Two hypotheses that focus on different but related aspects of the various encoding conditions were investigated. First, we hypothesized that all of the elaborative encoding methods (i.e., all of the conditions except naming) would result in a deeper level of encoding and thus improve the ability of patients with frontal lobe damage to perform recency judgments. Second, we hypothesized that SPT and perhaps one other encoding technique (depending on the critical SPT feature) would be the most efficacious methods.

Method

The study was conducted in two phases. It was important to select a condition order that prevented some specific encoding techniques from contaminating others that were particularly vulnerable. For example, if subjects became experienced at imagery and elaboration early in the test session, it would be difficult for us to prevent (and detect) them from covertly using the techniques while simultaneously performing actions in the SPT condition or naming the objects. Therefore, to assess whether there were any order effects, in the first phase we administered all five conditions in three different orders to three groups of 5 normal controls. The orders were constructed so that no condition occurred in any serial position more than once. Furthermore, SPT, the condition of primary interest, was distributed across serial conditions so that it occurred first, third, and fifth. The orders used were as follows: (a) SPT, naming, EPT, elaboration, imagery; (b) naming, EPT, SPT, imagery, elaboration; and (c) elaboration, imagery, naming, EPT, SPT. We performed a two-way (3 orders $\times$ 5 conditions) mixed analysis of variance (ANOVA) to determine whether there were any statistically significant differences among the three predetermined orders and five conditions. The order, $F(2, 12) = 1.34$, $p = .29$, condition, $F(4, 48) = 1.22$, $p = .31$, and Order $\times$ Condition interaction, $F(8, 48) = 0.91$, $p = .51$, effects all failed to attain statistical significance. Thus, no differences in normal controls' performance were found, regardless of condition or order. The order was fixed during the second phase, in which the task was administered to additional normal control subjects and to patients with frontal lobe damage.

Subjects

The second phase of the study examined the performances of 10 healthy normal control subjects and 10 subjects with circumscribed lesions in either the right or left frontal lobe or both frontal lobes. Exclusionary criteria for both groups included significant history of psychiatric disorder, alcohol abuse, or illicit drug use. In addition, none of the controls had a significant neurologic history (involving the central nervous system). The patient and control groups were matched for age, education, gender, and handedness. A series of univariate analyses (t tests) revealed no statistically significant differences between the groups in terms of age ($p = .59$) or education ($p = .40$). The groups had similar sex (normal controls: 6 men and 4 women; patients: 7 men and 3 women) and handedness (normal controls: 8 right and 2 left; patients: 9 right and 1 mixed) distributions.

The patients' lesions had a variety of etiologies, including anterior communicating artery aneurysm rupture and clipping (3), cerebrovascular accident (CVA) (3), tumor resection (2), and penetrating head injury (2). The time elapsed since initial illness or injury ranged from 2 months to 16 years, with a mean of 3 years 6 months. For lesion localization we followed the procedure of Damasio and Damasio (1989). Results of lesion analyses are summarized in Appendix A and Figure 1.

All patients were administered a neuropsychological battery (see Table 1) that included measures sensitive to cognitive abilities associated with frontal lobe dysfunction as well as tasks designed to assess specific cognitive functions relevant to the experimental task. Published norms, where available, were used to interpret the scores, and scores greater than one standard deviation below the mean were considered to be impaired. Patients' performance across the measures varied greatly. Four patients received relatively low scores on the measures of intellectual functioning, probably attributable to low levels of education in 3 of the cases (R.G., S.C., and C.H.) and to word-finding difficulty in 1 patient who had suffered a left frontal lobe CVA (A.L.). Three of the 10 patients (S.H., M.P., and R.S.) were minimally impaired both overall and, in particular, on the frontal lobe tasks. Seven patients were moderately impaired, showing deficits on some of the memory measures; but none was impaired across all memory tasks. On

Figure 1. Patient lesion reconstructions from computed tomography or magnetic resonance imaging scans. Solid area = region of documented damage; cross-hatching = region of peri-tumor edema; hatching = region of presumed damage (area obscured by aneurysm clip). Letters represent individual patients.

measures of frontal lobe functioning, 9 of the 10 patients performed in the impaired range on at least one task.

Materials

Two hundred common household objects were used to create five sets of items. Items were randomly assigned to one of the five sets, which were then fixed. Each set contained two lists (Lists A and B) of 10 target items each, for exposure during both the study and test phases, and an additional 20 items that were used as foils exclusively during the test phase. Target items were counterbalanced so that all lists appeared equally often in all conditions and in both positions (as Lists A and B). The sets of items are presented in Appendix B.

Procedure

Every subject participated in each of five different conditions. The five conditions differed in the encoding technique used during the study phase and were administered in the following order: an SPT condition, in which subjects performed an action with each item; a control (naming) condition, in which subjects simply named each item; an EPT condition, in which subjects observed the examiner perform an action with each item; a verbal elaboration condition, in which subjects judged how frequently they performed particular actions with items; and a visual imagery condition, in which subjects imagined themselves performing an action with each item. The actions involved in all of the conditions except naming were specific to the items and held constant across subjects and conditions.

Each condition consisted of a study phase during which the subject was exposed to 10 of the test items and their associated actions in a predetermined random order, designated as List A. The items were exposed one at a time, for 5–8 s each, with a 2–3-s interitem interval. After exposing subjects to List A, we had them count backward for 1 min to prevent rehearsal. They were then exposed to 10 more items (List B) in the same manner as for List A. Immediately following exposure to List B, subjects were tested. During the test, subjects were exposed to 20 pairs of items. Each pair consisted of one item from either of the presented lists, along with a foil they had not seen previously. Foil order was random. For target items, however, there was a standardized relationship between position at study and position in the test. This assured that item intervals between study and test exposure were held constant across all conditions and subjects. For each pair, subjects first indicated which of the items they recognized from the study phase. They then made a recency judgment for the recognized item, indicating whether the item was from List A or List B. Only those items correctly recognized were included in the recency judgment scores.

The procedure took approximately 2 hr to complete, and subjects were informed of the nature of the task. The instructions varied slightly, depending on the particular condition:

> I am going to [hand/show] you a series of objects, one at a time, and you will [perform a common action with it/ simply tell me its name/ watch me perform an action with it/ use a scale to rate how often you use it and to indicate the last time

Table 1
Patient Descriptive Data and Neuropsychological Test Scores

Variable or test	C.R.	Z.S.	S.H.	R.G.	S.C.	A.L.	M.P.	C.H.	M.N.	R.S.
Gender	M	M	F	M	F	M	M	F	M	M
Handedness	R	R	R	R	R	Mix	R	R	R	R
Age (years)	53	75	52	51	16	67	64	31	46	66
Education (years)	13	9	12	8	10	15	14	9	12	10
WAIS–R (age-scaled score; intellectual functioning)										
Information	9	10	9	7	6[a]	8	13	4[a]	8	14
Vocabulary	11	11	8	7	6[a]	8	15	5[a]	9	10
WMS–R (percentile; recall memory ability)										
LM 1	53	86	66	9[a]	47	11[a]	44	3[a]	9[a]	89
LM 2	38	81	45	23	49	14[a]	18	1[a]	8[a]	78
VR 1	19	90	63	50	43	12[a]	99	17[a]	72	89
VR 2	10[a]	99	80	65	79	49	13[a]	25	19	93
Recognition Memory Test (scaled score; recognition memory)										
Words	10	8	13	3[a]	10	13	9	13	10	11
Faces	4[a]	6[a]	9	5[a]	6[a]	9	11	13	4[a]	16
Cancellation task (raw score out of 30; attention; frontal lobe)										
Left	29	29	29	28	30	29	30	29	30	30
Right	30	30	28	22[a]	29	30	30	29	30	29
Trail Making Test (*T* score; frontal lobe)										
Trails A	41	58	42	43	53	38[a]	49	20[a]	41	38[a]
Trails B	33[a]	48	46	45	53	30[a]	49	10[a]	42	48
Stroop Color–Word Interference Test (*T* score; frontal lobe)	49	NA	51	48	55	—[b]	54	41	52	52
Letter fluency (percentile; frontal lobe)	95	9[a]	29	95	4[a]	4[a]	19	4[a]	4[a]	59
Luria tasks (raw score out of 20; frontal lobe)										
Alternation	15[a]	20	17	17	20	19	20	16[a]	20	19
Tapping	20	20	16[a]	20	17	18	17	20	16[a]	18
Go–no-go	20	18	20	20	20	15[a]	20	15[a]	19	20
Serial patterns										
Copy	20	20	20	18	20	19	19	17	12[a]	18
Recall	20	20	20	10[a]	20	20	20	10[a]	10[a]	20
Sensory–Perceptual Exam (prerequisite for SPT condition)										
Tactition (raw score out of 24)										
Right	24	24	24	22	24	24	24	24	24	24
Left	24	24	24	22	24	24	24	24	24	24
Audition (raw score out of 8)										
Right	8	8	8	6	8	8	8	8	8	—[b]
Left	8	6	8	6	8	8	8	8	8	—[b]
Vision (raw score out of 24)										
Right	24	24	24	22	24	24	0[a]	24	24	24
Left	24	24	24	24	24	24	24	24	24	24
Finger gnosis (raw score out of 20)										
Right	20	20	20	20	20	20	20	20	20	20
Left	20	20	20	20	20	20	20	20	20	20
Stereognosis (raw score out of 6)										
Right	5	4	NA	NA	4	4	NA	4	5	6
Left	5	5	NA	NA	4	4	NA	6	6	6
Finger oscillation (*T* score; frontal lobe)										
Right	44	44	36[a]	12[a]	36[a]	31[a]	50	24[a]	40	33[a]
Left	31[a]	51	40	10[a]	31[a]	52	47	27[a]	35[a]	37[a]
Grip strength (*T* score)										
Right	43	44	40	22[a]	30[a]	41	45	35[a]	37[a]	47
Left	44	46	40	13[a]	25[a]	43	47	50	43	48
Self-report imagery measure (*T* score; prerequisite for imagery condition)	62	63	58	60	57	45	60	62	60	51

Note. M = male; F = female; R = right-handed; WAIS–R = Wechsler Adult Intelligence Scale—Revised; WMS–R = Wechsler Memory Scale—Revised; LM = Logical Memory; VR = Visual Reproduction; NA = not administered; SPT = subject-performed task.
[a] Impaired. [b] Patient was too impaired to complete.

you used it/ imagine that you are performing an action with it]. We will call this series the first group. We will then take a 60-second break, during which you will count backwards. Immediately following the break, I will [hand/show] you another series of objects, one at a time, which we will call the second group. After [using/seeing] all of the objects in the second group, there will be a simple test, in which I will hold up pairs of objects. Each pair will consist of one item which you have seen already, and another which you have not seen before. I will ask you first to tell me which one you have seen, and then whether you think it was in the first group or the second group.

Results

The recognition memory performance of all subjects in all conditions was 100%; therefore all recency judgment items were available for analysis. For the recency judgment data (see Table 2), a two-way (2 groups × 5 conditions) mixed ANOVA revealed a significant overall effect of group, $F(1, 18) = 19.02$, $p = .0004$, which indicated that patients' performance was generally lower than controls'. There was no significant overall effect of condition, $F(4, 72) = 2.00$, $p = .10$. Importantly, there was a significant group-by-condition interaction, $F(4, 72) = 3.33$, $p = .01$, indicating that patients' performance varied across encoding conditions, whereas normal controls were equivalent across conditions. Post hoc *t*-test comparisons revealed significant differences between the groups across all encoding tasks except for SPT. In the SPT condition, there was no significant difference between patients and normal controls ($p = .75$).

Although the patients' mean performance was better than 10 out of 20 correct across all five conditions (see Table 2), there was a considerable range among the individual scores (9–18). Therefore, we performed a series of Wilcoxon signed-rank tests comparing the numbers of patients whose performance fell above and below chance (i.e., 10 correct) in each condition. A significant number of patients performed above chance across all conditions (p values corrected for ties ranged from .0047 to .0164).

The relatively small patient group used in the present study prohibited us from performing statistical analyses to determine the correlation between lesion size and site, or neuropsychological status, and task performance. However, inspection of individual cases revealed that the temporal order performance of the 3 patients who were minimally impaired overall (S.H., M.P., and R.S.) was equivalent to that of the other patients. Thus, in this study there was no obvious relationship between other neuropsychological deficits and temporal order memory impairment. This is consistent with the frequently noted dissociation among frontal lobe deficits.

Case inspections also revealed that the 10 patients did not have the same pattern of temporal order performance across the encoding conditions. Four patients in particular, although impaired in their overall recency judgment performance, produced performance patterns across the encoding conditions that were somewhat different from those of the other patients. For 2 patients (C.R. and M.P.), recency judgment performance was best in the imagery condition and second best in the SPT condition. The best performance of 2 other patients (S.H. and R.G.) was equivalent in the SPT condition and another condition: R.G.'s performance was equivalent under the SPT and imagery conditions, and S.H. performed equally well in the SPT and EPT conditions. It is interesting that patients M.P., S.H., and R.G. all suffered anterior communicating artery aneurysm rupture and clipping, which typically damages the posterior ventromedial frontal lobe, including the basal forebrain and orbital frontal cortex. Patient C.R.'s lesion also involved deep white matter structures adjacent to the basal forebrain. Therefore, select involvement of deep limbic system structures in the frontal lobe may anatomically distinguish this subgroup from those with lateral, polar, and superior cortical damage. The performance of the 4 patients who did not demonstrate a clear SPT effect is contrasted with the performance of the remaining patients and normal controls in Figure 2.

Table 2
Recency Judgment Performance by Condition in Phase 2

	Patients		Controls	
Condition	*M*	*SD*	*M*	*SD*
SPT	15.5	1.8	15.8	2.4
Naming	12.9	2.8	16.2	2.2
EPT	13.0	1.6	16.7	1.9
Elaboration	13.0	1.3	16.1	1.9
Imagery	13.9	2.2	17.2	2.0
M	13.6		16.4	

Note. Values are raw scores out of 20 possible correct. Condition order was as follows: SPT, naming, EPT, elaboration, imagery. SPT = subject-performed task; EPT = experimenter-performed task.

Discussion

The major finding of the present study was that SPT was effective as an aid in the recency judgments of frontal lobe patients. Our data on the critical properties of SPTs extend McAndrews and Milner's (1991) finding that performing tasks with objects facilitated the recency judgments of frontal lobe patients.

McAndrews and Milner (1991) offered the explanation that a reminding process may have accounted for frontal lobe patients' superior recency judgment performance. This speculation is based on earlier findings that recency judgments for both preexisting (e.g., category membership) and novel (e.g., interactive images) associations are better than recency judgments for unrelated word pairs (Tzeng & Cotton, 1980; Winograd & Soloway, 1985). These findings suggested the interpretation that the presentation of the second member of the pair reminds subjects of the first member. Because McAndrews and Milner's study contained relatively few action items compared to named items in each series, the SPT items may have been quite distinc-

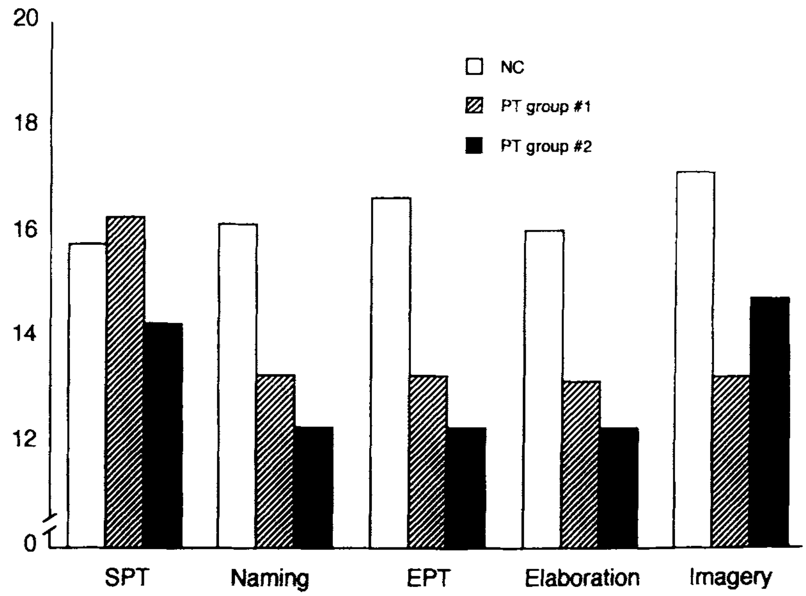

Figure 2. Temporal order memory performance across conditions. NC = normal controls; PT group #1 = patients (n = 6) who demonstrated a clear subject-performed task (SPT) effect; PT group #2 = patients (n = 4) who did not demonstrate a clear SPT effect; EPT = experimenter-performed task.

tive such that later SPT items reminded patients of earlier SPT items. This reminding process may have facilitated temporal order judgments. In the present study, items were blocked by condition so that SPT items were not distinctive relative to other items. Therefore, the process of reminding does not provide a good account of the present findings. Nevertheless, the possibility that SPTs provide more distinctive encoding than other elaboration techniques cannot be discounted. The nature of that distinctiveness, however, is the critical question.

Contrary to the hypothesis that the alternative distinctive encoding methods would improve the ability of frontal lobe patients to perform recency judgments, none of the elaborative techniques other than SPT substantially facilitated patients' performance. This lack of temporal order memory facilitation by conditions other than SPT is particularly interesting because there is evidence from studies on item recall that some of the encoding conditions used in the present study are equivalent to SPT in terms of their elaborative quality (Backman & Nilsson, 1984, 1985; Cohen, Peterson, & Mantini-Atkinson, 1987; Engelkamp, 1988; Saltz & Donnenworth-Nolan, 1981). Therefore, the SPT effect observed in the present study is not likely explained by general elaboration.

The second hypothesis more specifically addresses the critical properties of SPTs. We hypothesized that SPT and perhaps one other encoding technique (depending on the critical SPT feature) would be the most efficacious methods. No condition other than SPT was effective, which has implications for determining the critical feature. The movement-through-space and self-involvement aspects can be ruled out as crucial characteristics of SPTs. Because neither visual imagery nor verbal elaboration facilitated temporal order memory in the present study, it is unlikely that self-involvement was the feature critical for SPTs' effectiveness. The visually perceived movement-through-space component of SPTs can also be eliminated, because the EPT and visual imagery conditions did not improve patients' performance. Perhaps the crucial component of SPTs for the performance of recency judgments is the motor feature. Only SPTs required the activation and execution of motor programs (other than those required for speech), and these may have been what allowed patients to overcome or circumvent their deficit and perform recency judgments normally.

A number of possible explanations regarding motor programming may account for the effectiveness of SPTs. The first draws on three areas of relevant literature—temporal order memory in normal individuals, SPTs in normal individuals, and cognitive deficits associated with frontal lobe damage. Normally, both automatic and effortful processes are thought to be involved in temporal order memory (Jackson, Michon, Boonstra, De Jonge, & De Velde Harsenhorst, 1986; Naveh-Benjamin, 1990). Patients with frontal lobe damage often fail to engage in effortful processing (Fuster, 1989; Stuss & Benson, 1986), which may account for their temporal order memory deficit. In fact, effortful encoding did not lead to improved temporal order memory performance in the frontal lobe patients in the present study. Because SPTs appear to rely largely on automatic processes (Cohen, 1981, 1983, 1985), information about temporal order may be acquired automatically, resulting in improved performance.

Another compatible explanation for the efficacy of SPT is provided by considering the role of the basal ganglia. The basal ganglia receive powerful projections from the frontal lobe as well as nonfrontal sensory association and limbic cortices (Alexander, Crutcher, & DeLong, 1990; Goldman & Nauta, 1977; Yeterian & Van Hoesen, 1977). In addition, these cortico–striatal connections feed back to the frontal lobes via the pallidum and thalamus, creating a circuit. Recent research has indicated that several cortico–striatal loop circuits are involved in the activation and execution of simple and complex motor programs. At least one of these loops has been hypothesized to mediate certain forms of procedural or motor memory (Cummings & Benson, 1990; Domesick, 1990). The sensorimotor linkages from SPTs may involve a strong procedural representation, which is supported by the cortico–striate system and in some way facilitates recency discrimination in patients with limited prefrontal lobe damage. Future studies with patients who have damage to various components of the cortico–striate system may shed further light on the mechanisms responsible for SPT's effectiveness.

In the present study SPT appeared first in the condition order, and thus the possibility that the observed effect in patients may be attributed to proactive interference should be considered. If this were the case, performance would be expected to decline across the remaining conditions, eventually reaching chance level (in this case a score of 10). These data do not fit this pattern. Patient performance was statistically above chance and equivalent across all four of the non-SPT conditions. Therefore, it is unlikely that proactive interference accounts for the superior performance by the frontal lobe patients in the SPT condition.

There are a number of limitations of the present study. The investigation of temporal order memory under different conditions required adequate and equivalent performance across groups on item recognition memory. Unfortunately, this necessary ceiling effect prevented examination of SPT effects on item recognition memory.

The recent literature on temporal ordering in normal individuals indicates that numerous components and processes are involved. Furthermore, all temporal ordering tasks may not be tapping the same processes. For example, list discrimination judgments may rely on contextual cues other than recency, such as strength of association between items. Relative order may be encoded through a process separate from that used to encode more specific and elaborate temporal information (Jackson et al., 1986; Naveh-Benjamin, 1990). The recency judgments performed in the present study required only a judgment about relative position and did not assess subjects' ability to recall item serial position. Therefore, the SPT effect may not generalize to a more specific (and perhaps more difficult) temporal ordering task. If current theoretical notions are correct (cf. Jackson et al., 1986; Naveh-Benjamin, 1990; Zacks, Hasher, Alba, Sanft, & Rose, 1984), and the encoding of complex temporal order information normally requires effortful processing, it remains to be seen whether an automatic encoding method such as SPT can help patients compensate for their deficit on a more complex serial ordering task.

The small number of patients and the heterogeneity of their lesions represent another limitation. It is difficult to speculate from the present data about the involvement of specific prefrontal areas in temporal order memory. Milner et al. (1991) recently extended earlier findings that demonstrated the relationship between the presence of frontal lobe damage and deficits in memory for temporal order, by examining whether the mid-lateral frontal cortex is the critical area for temporal ordering ability. They administered a version of their original task (Milner, 1971, 1982) to 117 patients who had undergone unilateral cortical excisions involving frontal, temporal, or combined frontotemporal areas, and they examined the results based on lesion location. They found strong evidence that the mid-lateral frontal cortex in the left hemisphere plays a critical role in performing recency judgments for concrete words. However, there was no localizing evidence when the stimuli consisted of representational drawings. The most striking finding involved recency judgments for abstract drawings. Although the right frontal lobe was critically involved in the performance of recency judgments, there was no evidence that the mid-lateral frontal cortex made any special contribution.

Given the considerable recent discussion of the regional specificity of lesion effects within the frontal lobe (see Cummings, 1993; Fuster, 1989; Grattan & Eslinger, 1991), replication of the present study with a larger sample of patients with variously located frontal lobe lesions would be of interest. Such research would allow evaluation of the possibility, suggested by the preliminary observation in the present study, that SPT improvement may occur in different patterns for cortical versus deep limbic sites of frontal lobe damage. Also, future studies should investigate whether it is the size or the placement of the lesion that is the critical factor in determining whether a patient will demonstrate the SPT effect.

Finally, the use of only one patient sample made it impossible for us to demonstrate a double dissociation and to eliminate the possibility that both the deficit and the SPT effect were due to the mere presence of brain damage or subsequent general cognitive deterioration. This is unlikely, however, given that the present finding of a temporal order memory deficit in frontal lobe patients paralleled findings in earlier studies that included additional patient groups. However, future studies with varying sources and sites of brain damage are indicated.

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Appendix A

Patient Lesion Descriptions

C.R.: Right frontal lobe cerebrovascular accident (CVA) in the region of the operculum, which extends through the deep white matter to the frontal horn–subventricular area and to the insula with its subcortical structures, that is, the extreme and external capsules, claustrum, and so forth.

Z.S.: Left prefrontal lobe CVA, which is primarily cortical and in the inferior–lateral sector. There is only a small amount of white matter involvement.

S.H.: Rupture and clipping of anterior communicating artery aneurysm. Small left posterior ventromedial frontal lobe lesion, partly involving the basal forebrain.

R.G. and M.P.: Rupture and clipping of anterior communicating artery aneurysm; areas of damage are based on neurosurgeons' reports. Computed tomography scans show clip artifact that precludes precise lesion localization. Damaged area is typically posterior ventromedial frontal lobe, including the "basal forebrain", that is, septal nuclei, diagonal band of Broca, fornix, and so forth.

S.C.: Penetrating head injury resulting in bilateral damage to the orbitofrontal lobe. The lesion is polar and medial in the left hemisphere. The right-sided lesion extends through deep white matter, reaching the frontal horn, and stretches from medial to lateral surfaces.

A.L.: Left frontal lobe CVA involving the operculum (Areas 44 and 45) and extending in the deep white matter to the frontal horn, insula, and prefrontal cortex just rostral and dorsal to Broca's area.

C.H.: Left superior frontal lobe tumor, located at the superior mesial juncture of primary motor, premotor, and prefrontal cortices, compromising small portions of each. The inferior aspects of the lesion intrude on posterior cingulate gyrus and supraventricular white matter.

M.N.: Penetrating head injury resulting in large bilateral medial frontal lesions that extend upward from orbitofrontal cortex. The superior extension is greater in the right hemisphere than in the left. There is compensatory enlargement of lateral ventricles, particularly anteriorly.

R.S.: Large tumor extending to the orbital and inferior medial frontal lobe bilaterally. Edema surrounds the lesion, involving almost the entire inferior frontal lobe in polar, mesial, and lateral sectors. This includes the posterior ventromedial frontal lobe and possibly the region of the basal forebrain.

Appendix B

Recency Judgment Task Objects and Actions

Set 1

Study List A

bar of soap (wash hands)
pencil eraser (erase)
sunglasses (put on/take off)
big spoon (stir pot/serve food)
toothpick (use)
toilet brush (scrub toilet)
earphones (put on/listen to music/take off)
racquet (swing)
toy syringe (inject)
nail clippers (clip fingernails)

Study List B

Magic 8 Ball (turn over, read fortune)
safety pin (attach/remove from clothing)
plastic pear (eat it)
paper towel roll (tear towel/wipe hands)
container of Comet (shake/scrub table)
hair dryer (dry hair)
light bulb (screw/unscrew)
yo-yo (play with it)
flag (wave)
chopsticks (eat)

Test Foils

egg timer
tin foil
telephone
winter scarf
Post-it note
postage stamp
garden spade
clip
blackboard eraser

(*Appendix B continues on next page*)

Set 1 (*continued*)

cheese slicer
magnifying glass
TV remote control
watercolor paints
play money on money clip
compass
tablecloth
dish towel
doormat
hole punch
dice

Set 2

Study List A

paper clip (clip paper)
baseball (throw/catch)
ring (put on/take off finger)
bubble wand (blow bubbles)
globe (spin/find a location)
bell (ring)
ice cream scoop (scoop and serve ice cream)
nailbrush (scrub nails)
ball of string (unwind/wind)
shampoo (wash hair)

Study List B

box of tissues (remove tissue and blow nose)
button with slogan (pin on self)
ruler (draw a straight line)
eye patch (put on/take off)
pot holder (remove pot from stove)
box (open & close)
Rubik's Cube (attempt to solve)
thumbtack (push/pull from piece of cork)
shoehorn (put on shoe)
whisk broom (sweep)

Test Foils

back scrubber
toothpaste
hand mop
ribbon
comb
hand mirror
bottle opener
crayon
lobster bib
noisemaker
laundry bag
baseball bat
tongs
squeegee
jar
hand-held vacuum cleaner
pennies
high flyer/paddleball
hand blender
plastic donut

Set 3

Study List A

White Out (use on paper)
combination lock (spin dial/open)
Frisbee (throw)
pliers (remove nail from board)
can of soda (drink)
kaleidoscope (gaze into it)
colander (toss food to strain)
bottle of aspirin (remove and take one)
snow dome (shake it)
balloon (blow it up)

Study List B

spray bottle (spray surface/wipe)
stethoscope (listen to heart)
record (remove from sleeve/put on turntable)
bubble paper (wrap object)
alarm clock (wind)
feather duster (dust)
handkerchief (fold/put into breast pocket)
ace bandage (wrap arm)
fan (open and use)
fly swatter (swat a fly)

Test Foils

toothbrush
rubber ball
talcum powder
portable hose
top
candle
glue
hanger
can opener
Silly Putty
pencil sharpener
sponge
earmuffs
hammer
large salad utensils
playing cards
large tote bag
binoculars
party favor
apron

Set 4

Study List A

mouthwash (gargle)
ballpoint pen (click top and write)
tea bag (make tea)
pizza slicer (cut pizza)
name label (peel off/put on self)
twist tie (twist)
socks (make ball)
chalkboard (write on it with chalk)
flashlight (shine)
bandanna (tie around neck)

Set 4 *(continued)*

Study List B

nose clip for swimming (put on/take off)
Q-Tip (clean ear)
telescope (gaze at sky)
knife (cut food)
lint roller (remove lint from clothing)
envelope (address/lick it)
water pistol (shoot it)
tweezers (remove splinter)
key (unlock and open door)
clothespin (hang clothes on line)

Test Foils

wrench
carrot peeler
camera
stapler
rubber glove
rubber band
plastic fork
extension cord
magazine
tape measure
watering can
ice cube tray
shoe polish/buffer
clipboard
dishwashing liquid
stopwatch
umbrella
self-closing plastic bag
nutcracker
pepper grinder

Set 5

Study List A

dustpan (scoop up dirt/empty)
corkscrew (open bottle)
Slinky (play with it)
Band-Aid (put on self)
large paintbrush (paint wall)
matches (strike/blow out)
baseball cap (put on/take off)
roll-on antiperspirant (roll on)
mask (put on/take off)
screwdriver (turn screw)

Study List B

napkin (unfold, put on lap/dab mouth)
knapsack (place over/remove from shoulder)
air freshener (spray)
Scotch tape (tear off piece and put on paper)
bicycle horn (squeeze)
suntan lotion (apply)
change purse (open and close)
ladle (serve soup)
plunger (use it)
horseshoe (toss)

Test Foils

football
shoe
jump rope
scissors
flower
cotton ball
watch
needle and thread
map
ice scraper
sandpaper
calculator
straw
dental floss
belt
liquid dispenser
iron
razor
plastic food container
paint roller

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