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Automatic and Controlled Verbal-Information Processing in Patients With Frontal Lobe Lesions

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ABSTRACT. The selectivity of frontal lobe lesion effects in the domains of verbal-information processing has not been well established. The authors hypothesized that capacity-limited controlled processing would be more impaired than automatic processing in frontal lobe patients (FLPs). Fifteen FLPs were compared with 2 matched control groups: 14 posterior-lesion patients and 15 normal controls. Both behavioral and event-related brain potential (ERP) measures were collected. Results suggest that both automatic and controlled processing were affected by frontal lobe lesions. ERP results indicated that the main difficulty for the FLPs was in the perceptual stage of information processing. This rather unexpected result may be explained by a basic difficulty of FLPs in attending to a new stimulus in order to process it.

Key words: cognitive neuroscience, evoked potentials, frontal lobes, neuropsychology

IN THIS STUDY, the authors investigated the selectivity of frontal lobe lesion effects in the domains of automatic and controlled processing. Luria (1980) noted that lesions in the frontal lobes mostly affect self-generated control processes. In their extension of Luria's theory, Norman and Shallice (1986) suggested that a supervisory system, which is the "chief executive" of the brain, handles nonroutine behaviors when there is no known solution to the task at hand and when inappropriate schemas must be inhibited. According to this model, automatic contention scheduling refers to processes in which schema selection is triggered directly by the data and involves so little activation that the

behavior can be realized in parallel to other activities. Evidence suggests that frontal lobe lesions impair activation of the supervisory system (Shallice & Burgess, 1991a, 1991b, 1996; Stuss, 1991).

A recent study and meta-analysis conducted by Park, Moscovitch, and Robertson (1999) showed that people with severe traumatic brain injuries are impaired on nonroutine tasks requiring a high degree of controlled processing, but they are unimpaired on routine tasks that can be performed relatively automatically. Following Moscovitch's component process model of memory (Moscovitch, 1992, 1994), Park et al. (1999) related their results to the role of the central system frontal lobe component that allows for information to be inspected, enables performance to be controlled, and requires cognitive resources for its operation.

The distinction between contention scheduling of routine operations and supervisory control of nonroutine operations resembles the automatic/controlled dual-process model of Schneider and Shiffrin. Schneider and Shiffrin (1977) and Shiffrin and Schneider (1977) offered compelling evidence for a dual-process theory that differentiates between two qualitatively different human information-processing operations—"automatic detection" and "controlled search." Acquiring a new skill primarily entails the use of controlled search. Gradually, while the individual is mastering the skill, its processing becomes more automatic, enabling the individual to carry out another task simultaneously ("dual-task performance").

Automatic processing is used for skilled behaviors. It subsumes detection of familiar stimuli and initiation of a proper response. Automaticity is not limited by short-term memory capacity, allows for parallel processing, and is faster than controlled processing. It is unintentional and unconscious and therefore is not subject to control, cannot be avoided, and cannot be terminated in its course (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). Automatic processing is the result of extensive training in exactly the same task (Schneider & Fisk, 1982). Thus, it activates nodes in memory but does not modify long-term memory (Fisk & Schneider, 1984).

Controlled processing includes effortful attentional memory search, learning, and decision making. Controlled processing is slow and serial (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977), as well as sensitive to task difficulty, which limits dual-task performance (Fisk & Schneider, 1983). Controlled processes are, by definition, under active and direct individual control. Thus, they allow for task interruption in the course of performance and are preferable for handling novel or inconsistent situations.

However, there is hardly any task that is performed exclusively by use of automatic or controlled processes (Schneider, Dumais, & Shiffrin, 1984). There-

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fore, referring to a process as automatic or controlled is an oversimplification. In the present article, "automatic" and "controlled" will be used in relative rather than absolute terms (i.e., the automatic condition is more automatic than the controlled one). Nevertheless, the performance pattern for a given task will be different if the individual depends more on automatic or controlled processing.

It must be noted that Schneider and Shiffrin did not suggest specific brain areas for the different processing strategies. As far as we know there are no published studies that directly tested the dual-process theory using appropriate tasks with patients with frontal lobe lesions (FLPs). Because controlled processing is capacity limited, fatigue, motivation, drug abuse, and workload, as well as brain damage, almost always affect controlled processing rather than automatic processing. However, studies with various paradigms of FLPs have led to inconclusive results. Some have suggested that controlled processing is impaired, while automatic information processing is spared (e.g., Shallice & Burgess, 1991a, 1991b, 1996; Stuss & Benson, 1986; Stuss, Shallice, Alexander, & Picton, 1995). Yet, there is also evidence to suggest that FLPs have an automatic processing impairment (Knight, 1984, 1991). Based on the Norman and Shallice (1986) supervisory attentional system model and the previously mentioned neuropsychological evidence, we hypothesized that FLPs would have difficulty with controlled processing but not with automatic processing.

In this study, both behavioral and event-related brain potential (ERP) measures were collected. ERP is a recording of the brain's activity following the presentation of a stimulus, used to evaluate psychological processes (Donchin & Israel, 1980). Behavioral data usually include response time and accuracy. These measures reflect the end result of cognitive and motor processes and do not allow any insight into the real-time process. As such, poor results cannot be attributed to any specific stage of processing or even to general slowness. Rather, ERPs provide evidence of the allocation of attentional resources over the course of time in stimulus processing (Naatanen, 1986).

Several studies have examined the dual-process theory using ERPs. Hoffman, Nelson, and Houck (1983) examined the latency and amplitude of P300 ERP components during automatic and controlled training. The P300 is regarded as a measure of basic cognitive activities (Donchin, 1981). P300 latency data indicated that the development of automatic processing substantially reduces stimulus evaluation time. However, large P300 components were observed in automatic processing as well, indicating the involvement of a limited-capacity system in some aspect of performance in both types of search tasks.

Strayer and Kramer (1990) found that memory load influenced the controlled condition but not the automatic condition. P300 amplitudes were constant in all automatic conditions with different display sizes. In controlled conditions, however, the amplitude of the P300 reflected the workload, being larger for larger display sizes. In dual-task performance, P300 amplitudes were larger with the allocation of attention to one task. The fact that P300 amplitude was not affected by the experi-

mental manipulations (display size) supports the automaticity claim. Yet the results suggested that resources were used during automatic detection as well. Strayer and Kramer (1990) argued that the P300 ERP component during automatic processing appears to reflect the obligatory allocation of attention to task-relevant events.

On the basis of the dual-process theory of Schneider and Shiffrin, a distinction between automatic and controlled verbal-information processing was suggested by Neely (1977), who designed a lexical decision task that manipulated the automatic and controlled aspects of semantic activation. Neely found that certain target words, which were expected and semantically related to the prime words, were processed automatically, whereas other target words that were expected but not semantically related to the prime words were processed by using a controlled strategy.

To date, there are no published studies that have directly compared the automatic and controlled verbal-information processing of FLPs, using behavioral and ERP measures, within the framework of the dual-process theory. On the basis of Neely's (1977) findings, we created specific tasks for the present study, using semantic priming to generate automatic responses, while disruption of semantic priming was used to generate controlled responses.

To thoroughly investigate the phenomena, we generated two tasks with differing levels of difficulty. The easier task included only words representing colors, and the more difficult task included items of various semantic categories. In a pilot study with 10 students, the color task was performed significantly faster than the semantic task, thus establishing the different levels of difficulty for the two tasks. We hypothesized that group differences would be more pronounced in the more difficult task.

A Visual Oddball task was used as the ERP baseline task for all participants in this study. In the Visual Oddball task, participants were required to count target stimuli that were embedded randomly in a string of nontargets (two letters, with 20% of presentations being targets and 80% nontargets). This task usually elicits P300 ERP components for targets, reflecting allocation of attention to the task-relevant stimuli. In addition to measuring basic cognitive activities, the P300 is also highly correlated with various neuropsychological tests (Olbrich et al., 1986). Hence, a diminished P300, even in the baseline condition, suggests cognitive impairment (Pratap-Chand, Malliga, & Salem, 1988).

We assumed that in the present study, the differences between automatic and controlled processing would be maintained with longer latencies and larger amplitudes for the controlled category. Should the results point to FLP deficits in one type of processing only, that would offer dissociation between automatic and controlled processing and thus support the dual-process theories (Posner & Snyder, 1975; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977).

Hypotheses

1. For the behavioral measures, FLPs will have impaired controlled processing and thus will perform worse than both control groups in the response

time measures and will have lower accuracy rates in the controlled conditions, but not in the automatic conditions.

2. For the ERP measures, FLPs will have longer P300 latencies and larger P300 amplitudes than both control groups in the controlled conditions, but not in the automatic conditions.

3. For the Visual Oddball tasks, FLPs will have larger P300 amplitudes for the target stimuli than both control groups.

4. For task difficulty, there will be more group differences in the semantic (more difficult) task rather than in the color (easier) task.

Method

Participants

The present study included 29 participants with brain damage and 15 control group participants. The participants with brain damage (frontal and posterior lobes) were identified from the medical records of the neurosurgery department of Rambam Medical Center in Haifa, Israel, and were selected according to strict criteria. All had had brain surgery to remove meningioma at least 1 year prior to testing (i.e., they were in a chronic, stable condition). All participants were under the age of 61 years, all scored within the normal range on the Raven Standard Progressive Matrices (Raven, 1960), and none had any other known neurological or psychiatric diseases. FLPs were compared with two matched control groups: patients with posterior lobe lesions (PLPs) and normal controls (NCs). FLPs were 8 men (53%) and 7 women (47%), with a mean age of 48 years (*SD* = 10, range 23–60), 12.2 mean years of education (*SD* = 2.86, range 8–18), and mean time from operation of 6 years (*SD* = 7, range 2–29). PLPs were 8 men (57%) and 6 women (43%), with a mean age of 44 years (*SD* = 12, range 20–58), 13.1 mean years of education (*SD* = 2.79, range 7–18), and mean time from operation of 3 years (*SD* = 2, range 1–11). NCs were 9 men (60%) and 6 women (40%), with a mean age of 45 years (*SD* = 13, range 22–59), 14.1 mean years of education (*SD* = 2.07, range 12–16), and no known neurological or psychiatric diseases. All participants were Hebrew-speaking, right-handed, and with normal or corrected-to-normal vision. There were no significant differences between the three groups in age, gender distribution, or education. The Helsinki Committee of Rambam Medical Center approved the study, and each of the participants signed an informed consent form. University personnel and paid volunteers served as NCs.

Procedure

All testing and recording were conducted individually by the first author. Average time of testing was 4 hr for participants with brain damage and 3 hr for NCs. The participants were seated in a quiet room in front of an IBM personal computer (IBM-PC) screen on which stimuli were presented. They were in-

structed to remain quiet during the testing period and to refrain from moving. They were also told that it was important to avoid excessive eye movements and to avoid blinking as much as possible.

Tasks

Design of main tasks. In an attempt to thoroughly measure controlled and automatic information processing, we constructed two tasks of different levels of difficulty: a relatively easy color task and a more difficult semantic task. Each task consisted of four different categories. A semantic priming procedure was used in each category so that a distinct connection between a prime and the target words would be reflected, according to two dimensions: expectancy (expected or unexpected) and semantic relation (related or unrelated). Thus, the four categories were as follows: (a) Category 1: expected–related; (b) Category 2: expected–unrelated; (c) Category 3: unexpected–related; (d) Category 4: unexpected–unrelated.

In the color task, only words denoting colors were displayed, and in the semantic task only semantic categories were used (see Table 1). There were 20 pairs of words in each category of the color task (a total of 80 pairs) and 30 pairs of words in each category of the semantic task (a total of 120 pairs). Pairs of words from the four categories were randomly presented within each task. Each prime word was presented at the center of the screen for 500 ms, followed by 500 ms of black screen (stimulus onset asynchrony; SOA). This was then followed by presentation of a target word at the center of the monitor, which remained on display until the participant responded. After an ISI of 1000 ms, the next pair of words was similarly presented.

The instructions for the color task were as follows: "Two words will be presented one after the other. When the first word is '*red*,' the second word will also

TABLE 1
Task Design and Examples of Stimuli

	Category			
Task	1. Automatic expected–related	2. Controlled expected–unrelated	3. Inhibition unexpected–related	4. Distraction unexpected–unrelated
Color	red–red white–white	blue–green green–blue	blue–blue green–green	blue–yellow green–pink
Semantic	body–arm house–door	animal–doctor work–dog	animal–cat work–nurse	animal–book work–shoe

Note. Categories 1 and 2 are expected, and therefore the correct answers are "Yes." Categories 3 and 4 are unexpected, and therefore the correct answers are "No."

be '*red.*' When the first word is '*white,*' the second word will also be '*white.*' BUT, when the first word is '*blue,*' the second word should be '*green,*' and when the first word is '*green,*' the second word should be '*blue.*' All of these conditions are correct, and you should respond by pressing the right button. All of the other combinations are not correct for this task, so we will define them as 'incorrect,' to which you should respond by pressing the left button."

The semantic task followed the same structure, using semantic categories. The instructions were as follows: "Two words will be presented one after the other. When the first word is '*body,*' the second word will be part of the body (e.g., body–leg). When the first word is '*house,*' the second word will be a household item (e.g., house–oven). BUT, when the first word is '*animal,*' the second word should represent *an occupation* (e.g., animal–pilot), and when the first word is '*work,*' the second word should be an *animal* (e.g., work–dog). All of these conditions are correct, and you should respond by pressing the right button. All of the other combinations are not correct for this task, so we will define them as 'incorrect,' to which you should respond by pressing the left button."

Although there were four categories, we discuss only two categories in this article to distinguish between a more automatic and a more controlled processing. The first category (expected–related) represents automatic processing, and the second category (expected–unrelated) represents controlled processing. (The two other categories, used to evaluate distractibility phenomena of FLPs, will be addressed in a companion report.)

Visual Oddball baseline task. In the Visual Oddball task, stimuli were presented at a rate of 250 ms and an ISI of 500 ms. Target stimuli appeared 20% of the time (n = 20), and nontarget stimuli 80% of the time (n = 80). Participants were required to count the target stimuli, which consisted of two Hebrew block letters 6 mm high presented at the center of a computer screen.

Instrumentation

All stimuli were presented in white letters on a gray background on an IBM-PC computer display, located 1.5 meters in front of the participant. Participants responded by pressing two numeric keys (0 and 1).

EEG-Brain Atlas III. A total of 22 channels of electroencephalographic (EEG) activity were acquired, using a Bio-Logic Brain Atlas III computer system with brain mapping capabilities. This system used a bandpass of 0.1-100 Hz interfaced with a 20-channel 12-bit A/D converter and a notch filter of 50 Hz. The potentials were sampled at a rate of 250 Hz (dwell time = 3.9 ms), beginning 100 ms prior to stimulus onset. The recording epoch was 2,000 ms per trial.

A full array of electrodes were placed according to the 10/20 system (Jasper, 1958), utilizing an Electro-cap (a nylon cap fitted over the head with 9 mm tin

electrodes sewn within). During data collection, electrode impedance was kept below 5 Kh by first prepping scalp areas with a mildly abrasive cleanser (Omni-Prep) and then using an electrolyte gel (Electro-gel). Nineteen scalp electrodes were used: PF1, PF2, F7, F3, FZ, F4, F8, T3, C3, CZ, C4, T4, T5, P3, PZ, P4, T6, O1, O2. All were referenced to an electrode on CVII (the seventh cervical vertebra) and grounded to Fpz. In addition, one electrode was applied diagonally below the left eye to monitor eye movements. Trial onset was marked on the Oz channel of EEG via a positive polarity 5 millivolt pulse delivered from an IBM-PC 386 terminal. Signal averaging of the raw EEG data was performed off-line. EEG data were separated into discrete trials. After the eye movement correction, we calculated the average of the individual trials according to the research paradigm.

Evoked Potentials

We obtained evoked potentials for each participant in each category. We then used grand averaging across participants of each group in each task and each category to assess consistency of results across participants. Artifact rejection was performed on-line by the Brain Atlas software. Only single trials that were free of eye movements and associated with correct responses were averaged to obtain evoked potentials. ERP peak latencies were measured from stimulus onset, and amplitudes were measured relative to the mean voltage of each channel during the pre-stimulus baseline. For each component, the analysis was run on waveforms from the 19 scalp electrodes.

Data Analysis

Data analysis included four behavioral measures:

1. Response time to target words—from stimulus onset to pressing of a response key.
2. Accuracy—percentage of correct responses.
3. Response selection time—a measure of the response selection stage of processing was calculated as reaction time minus P300 latency (mean of the 19 electrodes).
4. Performance—a combined measure of response time and accuracy, which indicates the response time corrected for accuracy. Only correct answers were processed, which could have led to misrepresentation of performance. Theoretically, participants could work quickly but impulsively, which would result in more errors. Thus, looking at the response time for their correct answers alone would show very good results. To avoid this, we weighted response time with number of errors, according to the equation $P = R(2 - A/N)$, where P = performance, R = response time, A = accuracy, and N = total number of word pairs in the category. As an example, R = 1000 ms:

100% accuracy: 1000(2 – 30/30) = 1000; 50% accuracy: 1000(2 – 15/30) = 1500.

Performance is thus measured in ms, like response time, and the lower the accuracy, the longer the performance time.

ERP measures included amplitudes and latencies of N100 and P300 components. N100 was the most negative peak, between 100 and 150 ms, and P300 was the most positive peak, between 350 and 850 ms after stimulus onset.

Comparisons between groups were conducted separately for FLPs and each control group (PLPs and NCs). Repeated measures multivariate analyses of variance (MANOVAs) were calculated, with the 19 electrodes as measures.

Results

Visual Oddball Task

Results of the grand averaging of the Cz electrodes in the Visual Oddball task are presented in Table 2. Cz was chosen for presentation, as it is the most noticeable component of the Visual Oddball task. MANOVA calculations, however, included all 19 electrodes as measures.

Comparisons of the FLP and NC groups indicated that FLPs had significantly higher P300 amplitudes for both target stimuli, $F(1, 28) = 17.57$, $p < .001$, and nontarget stimuli, $F(1, 28) = 4.01$, $p < .05$. The groups showed a significant difference between results for targets and nontargets, $F(1, 28) = 7.85$, $p < .001$.

There were no significant differences found between the FLP and PLP groups when comparing targets and nontargets separately. There was, however, a significant difference in P300 amplitudes between target and nontarget stimuli, $F(1, 27) = 4.24$, $p < .05$, with FLP amplitudes smaller than those for PLP.

TABLE 2
Event-Related Brain Potential (ERP) Components of the Visual Oddball Task, by Group

	FLP		PLP		NC	
ERP component	*GA*	*SD*	*GA*	*SD*	*GA*	*SD*
Target stimuli						
P300 amplitude Cz	4.27	1.59	5.07	2.45	4.92	1.50
P300 latency Cz	474.13	73.43	461.93	60.42	461.27	34.79
Nontarget stimuli						
P300 amplitude Cz	1.75	.91	1.74	1.26	1.97	1.46
P300 latency Cz	433.73	86.24	427.43	69.93	380.20	48.87

Note. FLP = frontal lesion patients. PLP = posterior lesion patients. NC = normal control participants. *GA* = grand average—the ERP average for a group of participants. Amplitudes are in millivolts and latencies in milliseconds.

Main Tasks

Due to the large amount of data analysis performed, the numeric results are presented in tables, followed by a description of the main results. Behavioral results are presented in Tables 3 and 4, and grand averages of ERP components are presented in Table 5.

For group comparisons of each category separately, repeated measures MANOVAs were conducted, with the 19 electrodes used as measures for the ERP. Only statistically significant findings from the ERP results are presented in Table 6, along with the direction of the differences (i.e., whether the FLP group has higher or lower measures than the control groups).

Behavioral results indicated that FLPs were slower in response time and their overall performance was worse than the NCs in the color task, for the automatic category only, and in the semantic task, in both categories. In the semantic task alone, in both categories, FLPs were also significantly less accurate, and their response selection processing was significantly longer than for those in the NC group.

TABLE 3
Means and Standard Deviations of Response Time and Performance, and *F* Multivariate Analysis of Variance (MANOVA) of Group Comparisons

	Response time (ms)			Performance (ms)		
Task/category	FLP	PLP	NC	FLP	PLP	NC
			Color			
Automatic						
M	964.55	906.77	727.51	1104.3	958.4	806.7
SD	397.3	384.6	216.3	512.4	403.6	260.0
F		3.60*			3.97*	
Controlled						
M	1238.1	1055.2	998.89	1517.4	1246.3	1211.2
SD	650.4	357.8	518.8	877.2	457.9	892.5
			Semantic			
Automatic						
M	1759.9	1327.4	1000.9	2008.6	1401.2	1037.0
SD	914.4	348.4	379.9	1252	340.0	398.8
F		5.28**			8.18**	
Controlled						
M	2525.9	2145.1	1601.9	3434.8	3026.3	1884.5
SD	1066	1368	802.4	1742	2742	1288
F		4.12*			7.50**	

Note. FLP = frontal lesion patients. PLP = posterior lesion patients. NC = normal control participants. The table also includes MANOVA significant differences between the FLP and PLP groups, $F(1, 27)$, and between the FLP and NC groups, $F(1, 28)$.
*$p < .05$. **$p < .01$.

TABLE 4
Means and Standard Deviations of Accuracy and Response Stage, and *F* Multivariate Analysis of Variance (MANOVA) of Group Comparisons

	Accuracy (%)			Response stage of processing (ms)		
Task/category	FLP	PLP	NC	FLP	PLP	NC
			Color			
Automatic						
M	.86	.94	.90	414.14	406.85	225.89
SD	.09	.02	.10	352.7	400.4	264.2
F		10.56**				
Controlled						
M	.75	.78	.84	679.42	1068.4	485.55
SD	.27	.23	.20	641.5	1048	502.1
			Semantic			
Automatic						
M	.88	.94	.94	1157.8	755.55	417.19
SD	.13	.06	.04	929.2	375.0	367.9
F		5.52*			2.79*	
Controlled						
M	.67	.72	.88	1927.8	1551.8	1048.4
SD	.29	.32	.21	1094	1362	807.0
F		4.82*			2.45*	

Note. FLP = frontal lesion patients. PLP = posterior lesion patients. NC = normal control participants. The table also includes MANOVA significant differences between the FLP and PLP groups, $F(1, 27)$, and between the FLP and NC groups, $F(1, 28)$.
*$p < .05$. **$p < .01$.

ERP results show that in the automatic category of the color task, FLPs had longer N100 and P300 latencies than the NCs as well as smaller N100 amplitudes. In the controlled category of the color task, however, there were no significant differences between the FLP and NC groups. In the semantic task, in both categories, FLPs had longer N100 latencies than the NCs. In the controlled category alone, FLPs also had larger N100 amplitudes.

Comparisons of the FLP and PLP groups were also calculated. Behavioral results indicate no significant differences between the groups in the time measures. FLPs, however, were less accurate than PLPs in all the conditions, though statistical significance was reached only in the first category of the color task.

ERP results suggested that in the color task, for the controlled category, and in the semantic task, in both categories, FLPs had longer N100 latencies than

TABLE 5
Grand Averages and Standard Deviations of Event-Related Brain Potential (ERP) Components, by Group

ERP component	FLP		PLP		NC	
	GA	*SD*	*GA*	*SD*	*GA*	*SD*
			Color task			
Automatic category						
N100 amplitude Fz	–3.94	1.49	–5.01	2.20	–4.56	2.02
N100 latency Fz	126.40	11.90	115.07	7.84	114.14	7.27
P300 amplitude Cz	2.57	1.55	4.36	2.97	3.07	1.20
P300 latency Cz	583.27	167.0	471.86	174.2	474.14	172.0
Controlled category						
N100 amplitude Fz	–4.17	3.90	–5.42	2.80	–4.99	2.75
N100 latency Fz	117.20	10.24	113.93	10.89	111.14	8.08
P300 amplitude Cz	3.38	1.74	3.62	2.11	3.26	1.68
P300 latency Cz	610.93	157.6	456.29	124.1	568.79	138.6
			Semantic task			
Automatic category						
N100 amplitude Fz	–2.83	1.33	–3.10	1.41	–3.61	1.39
N100 latency Fz	117.20	11.89	116.36	10.23	114.40	11.66
P300 amplitude Cz	2.93	1.25	2.77	1.14	2.78	1.47
P300 latency Cz	581.33	137.0	582.71	105.9	599.93	87.63
Controlled category						
N100 amplitude Fz	–5.37	2.52	–1.58	2.24	–3.39	1.82
N100 latency Fz	117.87	10.47	120.00	9.91	115.60	9.68
P300 amplitude Cz	3.93	3.03	4.63	3.60	1.74	1.29
P300 latency Cz	604.13	145.6	580.71	147.6	600.67	116.5

Note. FLP = frontal lesion patients. PLP = posterior lesion patients. NC = normal control participants. *GA* = grand average—the ERP average for a group of participants. Amplitudes are in millivolts and latencies in milliseconds.

PLPs. In the semantic task, for the controlled category, FLPs also had larger N100 amplitudes.

Of special interest are the interactions between groups and categories. Two-way MANOVAs (Group × Category) were calculated for each variable of each task. In the color task, there was a Group (FLP vs. NC) × Category interaction for the N100 latency, $F(1, 28) = 3.33$, $p < .05$. FLPs had smaller differences than the NCs between the automatic and controlled categories, reflecting the longer FLP latencies of the automatic category compared with those of the NCs, as well as the absence of significant differences between the groups in the controlled category. In addition, in the color task, there was an interaction between the FLPs

TABLE 6
Multivariate Analysis of Variance (MANOVA) of Event-Related Brain Potential (ERP) Group Differences

	ERP component		
Task/category	N100 latency	N100 amplitude	P300 latency
Comparisons between FLP and NC groups, F(1, 28)			
Color			
Automatic	2.78* FLP > NC	3.77* FLP < NC	4.12* FLP > NC
Semantic			
Automatic	4.15* FLP > NC		
Controlled	5.28** FLP > NC	7.72*** FLP > NC	
Comparisons between FLP and PLP groups, F(1, 27)			
Color			
Controlled	3.60* FLP > PLP		
Semantic			
Automatic	4.73* FLP > PLP		
Controlled	3.13* FLP > PLP	3.06* FLP > PLP	

Note. FLP = frontal lesion patients. PLP = posterior lesion patients. NC = normal control participants. Repeated measures MANOVAs were calculated for each ERP component and for each task and category separately, with all 19 electrodes as measures. Because there were many calculations, only significant results are presented. Also included are the directions of the differences: a > b = a is significantly greater than b.
*$p < .05$. **$p < .01$. ***$p < .001$.

and PLPs for the N100 amplitude, $F(1, 27) = 4.75$, $p < .05$, again reflecting the fact that FLPs had larger N100 amplitudes in the automatic category only. In the semantic task, there was an interaction between the FLPs and NCs for the N100 amplitude, $F(1, 28) = 3.36$, $p < .05$, given the larger amplitudes of FLPs in the controlled category.

Summary of Results

1. For behavioral measures, FLPs performed worse than the control groups in the behavioral measures of both the automatic and the controlled categories.

In the automatic category, FLPs had lower performance than the NCs in all four behavioral measures of the semantic task, as well as in response time and performance measures for the color task. FLPs were also less accurate than the PLPs in the color task. In the controlled category, there were no differences between the FLPs and either of the control groups in the color task. However, there were differences in the semantic task, wherein FLPs performed worse than both control groups.

2. For ERP measures, FLPs had longer N100 latencies in both tasks than both control groups. FLPs also had larger N100 amplitudes than both control groups in the controlled category of the semantic task.

3. For the Visual Oddball task, FLPs had significantly larger P300 amplitudes than the NCs.

4. For the task difficulty, there were more differences between the FLP and the NC groups in the semantic task than in the color task.

Discussion

In this study, we attempted to determine whether both automatic and controlled verbal-information processing were impaired in FLPs. On the basis of the vast literature that links the frontal lobes with controlled processing (e.g., Luria, 1980; Shallice & Burgess, 1991a, 1991b, 1996; Stuss & Benson, 1986; Stuss et al., 1995), we hypothesized that FLPs would have impaired controlled processing. Accordingly, we expected group differences only in the controlled category. FLPs were expected to have longer response times and ERP latencies, reflecting a slowing in controlled information processing. FLPs were also expected to have larger P300 amplitudes than both control groups in the controlled categories, reflecting difficulties in the stimulus evaluation stage of processing. The results, however, proved otherwise: FLPs performed worse than the control groups in both categories, thus suggesting that both automatic and controlled processing were affected by frontal lobe lesions.

Because the prime-target relations of the automatic category were based on semantic activation (Collins & Loftus, 1975), it could be argued that FLPs did not benefit from automatic semantic activation. The behavioral results, however, established that FLPs processed items in the automatic category more rapidly than those in the controlled category in both the color and the semantic tasks.

The most consistent difference between FLP and both control groups was the N100 ERP component, which reflects allocation of attention in the perceptual stage of processing (Gazzaniga, Ivry, & Mangun, 1998). The fact that FLPs were slower in both tasks and in both categories indicates a general, rather than a specific, impairment. Because there is no neuroanatomic reason to propose that FLPs suffer from specific perceptual difficulties, it is suggested that the impairment reflects the inability of FLPs to focus and allocate attention to start processing a new stimulus. This explanation is in agreement with research findings

that FLPs have difficulty in novelty detection (Daffner et al., 2000; Knight, 1984, 1991). It has been proposed that frontal lobe damage leads to diminished visual attention to novel events, given the difficulty with allocation of attentional resources and early exploratory behaviors (Daffner et al., 2000). Damasio (1998) found that patients with ventromedial frontal lobe damage are impaired with the "somatic marker" (measured by skin conductivity). The somatic marker can act either overtly or covertly to "highlight, in the form of an attentional mechanism, certain components over others, and to direct, in effect the go, stop, and turn signals necessary for much decision making and planning" (Damasio, 1998, p. 43). Shallice and Burgess (1996) also incorporated an "intention marker activation," which is needed in decision making, as part of their supervisory process, although they have not specified the neurobiological nature of the marker. In line with those studies, the results of the present study offer ERP evidence for FLP difficulty in the focusing and allocation of attention required to start processing a new stimulus.

We expected the main differences between the groups to surface in the stimulus evaluation stage, that is, in the P300 ERP component. Specifically, we anticipated P300 latencies of FLPs longer than those of the NCs and smaller amplitudes, as was found by Olbrich et al. (1986) and Deacon and Campbell (1991a, 1991b). Contrary to expectations, no significant differences were found between FLPs and NCs in the P300 latencies of the main tasks. Several studies have found that shortly after the trauma, the P300 latencies of brain-damaged patients were lower than those of NCs, but these differences disappeared upon testing the same patients again in a chronic state (Onofrj et al., 1991; Pratap-Chand et al., 1988). The fact that all of our participants with brain damage were in a chronic state may explain their normal P300 results. Knight (1984) tested FLPs with the Auditory Oddball paradigm and did not find longer P300 latencies; likewise, these results were supported by Rugg et al. (1993).

The slowness of FLPs, reflected by response times longer than those of the NCs (but not the PLPs), is in accordance with a large body of literature indicating that brain lesions slow the speed of information processing. It cannot be attributed, however, to a global slowness (e.g., "global slowness hypothesis" of Van Zomeren & Brouwer, 1994), as there were no significant differences between the groups in the P300 latencies (except the difference between FLP and NC groups in the first category of the color task). Yet there were differences between the FLP and the NC groups in the response stage of the semantic task, suggesting a specific slowness in the response stage, rather than a general slowness of all three stages of processing.

We also hypothesized that the more complex or difficult the task, the more group differences would be found. There were, in fact, more differences between the FLP and the NC groups in the semantic task than in the color task, suggesting the effect of task difficulty on FLP performance.

In the Visual Oddball task, FLPs had significantly larger P300 amplitudes

than the NCs. In line with Naatanen's (1986) suggestion that amplitudes reflect allocation of attention, our results may indicate FLPs' excessive allocation of attention in the stimulus evaluation stage of processing the Visual Oddball task. Interestingly, the PLPs allocated even more attention than did the FLPs; perhaps both groups of participants with brain damage needed excessive allocation of attention for the Visual Oddball task, but the PLPs had more resources than the FLPs. Conversely, the posterior site of the lesion in the PLPs may have affected their visual cortical processing to a greater extent, demanding more attentional resources to perform the task properly.

The results of the present study do not offer strong neuropsychological support for the dual-process theory, as both automatic and controlled processing were impaired in the FLP group. Yet there were significant differences between the automatic and controlled categories in the behavioral measures for both tasks, in all three groups, as well as some ERP evidence to offer support for the dual-process theory.

Although this research focused on FLPs, interesting results emerged concerning the group with posterior lesions (for example, their relatively high P300 amplitudes in the Visual Oddball task). Future studies should address PLPs with finer definitions of affected cerebral loci.

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