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Automatic and Attentional Processing: An Event-Related Brain Potential Analysis of Semantic Priming

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Event-related brain potentials (ERPs) and behavioral measures (reaction time and percentage errors) were measured in a semantic priming lexical decision task. In one block of trials, instructions and the proportion of related word pairs were designed to influence subjects to process the first member of each pair (prime) automatically. In another block, subjects were induced to attend to the meaning of each prime. ERPs to the primes were more positive between 200 and 600 msec and more negative between 750 and 1150 msec when subjects attended to the primes as opposed to when only automatic processing was required. Target word ERP activity between 200 and 525 msec (N400) was more negative in the neutral than in the semantically related condition in both blocks of trials, but more so in the attentional block, while a late ERP positively between 525 and 1100 msec (Slow Wave) was more positive in the unrelated than the neutral condition, but only in the attentional block. The results are discussed in terms of the two-process model proposed by Posner and Snyder (1975a, 1975b).

Over the last decade a number of investigators have noted that the processing of a stimulus can be enhanced or "facilitated" when it is preceded by a related or predictive event and, in some cases, inhibited or "interfered" with when it is preceded by an unrelated or nonpredictive event (e.g., Taylor, 1977; Becker, 1980). Posner and Snyder (1975a, 1975b) were among the first to suggest that this pattern of results can

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be accounted for by a dual-process model where facilitation results, in part, from activity associated with the processing of the first event (or prime) "automatically" spreading activity to representations associated with the second event (or target). Posner and Snyder also suggested that facilitation beyond that attributable to automatic processes can occur if "conscious attention" is used in some aspect of the processing of the prime. This occurs because attentional resources can be flexibly utilized to enhance processing at several levels within the system. However, although flexible, conscious attention is unlike automatic processing in that it is relatively slow and of limited capacity, so while one event is receiving preferential treatment, similar processing of other events may be made more difficult.

Posner and Snyder's (1975a) work involved the use of single letters as stimuli. Other investigators have attempted to extend the Posner and Snyder model to the processing of words (e.g., den Heyer, Briand, & Dannenbring, 1983; Neely, 1976, 1977; Tweedy, Lapinski, & Schvaneveldt, 1977). Most of these studies, which have used the lexical decision task, have reported that subjects make faster responses (facilitation) when a target word is preceded by a semantically related prime word, but make only marginally slower responses (interference) when the prime is unrelated to the target.

There are at least two possibilities for this asymmetry in response measures, both of which stress the limitations of the techniques traditionally used to assess differences between conditions in these types of experiments. The first assumes that something like an interference process (or processes) may actually exist in the system, but that there is a lack of sensitivity in the measures (reaction time and errors), which are single discrete data points that occur at some unknown point after (or before) the processes of interest. A second possibility is that subjects may not have processed the primes as the experimenter intended. Without a more direct measure of prime processing it is difficult to know how subjects have reacted to passively read primes. Clearly what is needed is a noninvasive technique for measuring the processes that occur before, during, and after the

Event-Related Brain Potentials

The electrical activity of the brain time-locked to the presentation of a stimulus, the so-called event-related potential (ERP), has been shown to be sensitive to a variety of sensory and cognitive processes (e.g., Donchin, 1984; Regan, in press). Two related advantages of ERPs are that they reflect information processing as it happens and they are continuous in time allowing for simultaneous monitoring of changes associated with early and late information processes. An additional advantage is that ERPs can be recorded as the subject passively views a stimulus.

Early studies using ERPs sought to determine what variables or processes control various subparts or components of the waveform. Recently, a number of investigators have started to focus on what changes in specific ERP components can reveal about human information processing. Notable in this area are studies of language processing. Kutas and her colleagues (e.g., Kutas and Hillyard, 1980) have demonstrated that a negative going ERP component at approximately 400 msec (N400) is large whenever the final word of a sentence is semantically unexpected within the presented context and small when it is expected. Their interpretation is that N400 is inversely proportional to the level of automatic semantic activation provided by prior sentence context (Kutas, Lindamood, & Hillyard, 1985).

If N400 reflects semantic activation processes then it should be present even outside of a sentence context. Bentin, McCarthy, and Wood (1985) recorded ERPs in a semantic priming lexical decision task in which subjects made a word/nonword decision about each stimulus in the task. They found that words preceded by a semantically unrelated word were characterized by a more negative ERP deflection between 250 and 650 msec than were words preceded by a related word. Bentin et al. (1985) suggested that the scalp distribution of this difference and its morphology (waveshape) were similar to the Kutas' N400.

More recently Rugg (1984, 1985) and Boddy (1986) have reported similar N400-like negativities in variations of the lexical decision task. Boddy's experiment is interesting because he varied the prime-target interval (stimulus onset asynchrony-SOA) which has been shown to influence whether subjects use only automatic or both automatic and attentional resources to process the relationship between the prime and target (e.g., Neely, 1977). Data from this task may be useful in helping determine whether N400 reflects primarily automatic (as suggested by Kutas et al., 1985) or attentional processes. In agreement with the Bentin et al. (1985) study Boddy reported a large negativity (N340) for unrelated targets but found no effect of SOA suggesting that attentional processes did not have a differential effect on N400 amplitude. However, it should be noted that only one-third of the trials in Boddy's experiment contained related pairs. A number of studies have shown that a higher percentage of related pairs or some other manipulation of subjects' strategies is required in order to engage attentional processing of primes (e.g., den Heyer et al., 1983).

Another group of ERP studies has shown that a complex of positive components in the latency range of 250 to 1100 msec are sensitive to certain other "cognitive" processes. The amplitude of P300 has been demonstrated to be sensitive to the expectancy of an event and whether the event is to be attended or responded to (see Pritchard, 1981). The peak latency of the P300, on the other hand, has been shown to reflect the duration of the same set of processes up to response selection as reaction time (e.g., McCarthy & Donchin, 1981).

Duncan-Johnson and Donchin (1982) recorded P300 latency and RT in a task where target letters were preceded by either a matching letter, a neutral stimulus, or a mismatching letter. When the target letter matched a previously presented prime, neither P300 nor RT were earlier than in the neutral condition (i.e., there was no facilitation effect). However, both RT and P300 were later when prime and target mismatched compared to the neutral condition and this effect became larger, in accordance with the Posner and Snyder model, as the proportion of match trials increased. The authors pointed out that their failure to find a facilitation effect may have been due to the neutral condition producing some degree of facilitation itself (see Discussion section).

A number of studies have reported the existence of an ERP component that temporally overlaps the P300, but which has a later peak latency (0 to 400 msec after P300). In a systematic series of studies Ruchkin and colleagues have demonstrated that P300 reflects initial stimulus evaluation and a component they referred to as Slow Wave a later more "in depth" or reevaluation process that varies with task demands (e.g., Ruchkin, Sutton, Kietzman, & Silver, 1980a; Ruchkin, Sutton, & Stega, 1980b).

The experiment to be reported here was designed to explore changes in ERPs (and behavior) recorded to lexical stimuli under conditions requiring either automatic or attentive processing of the prime. Subjects were run in high and low validity blocks of trials (high and low proportions of semantically related trials) in a lexical decision task, and were given instructions intended to further induce the two types of prime processing (Paap and Ogden, 1981).

The five following predictions were made: (a) because P300 has been shown to be larger to attended than unattended stimuli even when the subject has not had to make an overt response to the event of interest (e.g., Holcomb, Dykman, Oglesby, & Johnston, 1981), it was predicted that primes which subjects were encouraged and instructed to attend to would be associated with larger P300 components than primes they were encouraged and instructed not to attend to; (b) because of its reported sensitivity to semantic priming (e.g., Bentin et al., 1985) it was predicted that the N400 component would be larger to words following semantically unrelated primes than to words following related primes; (c) because of the suggestion by Kutas et al. (1985) that N400 reflects primarily automatic processes it was predicted that target N400s would be the same amplitude in the automatic and attentional conditions; (d) because some attentional effects may take some time to become activated it was predicted that the long latency Slow Wave, which has been shown to reflect post-P300 effortful processing (e.g., Ruchkin et al., 1980a), would be maximally sensitive to these effects; and (e) because they have been reported to

TABLE 1

STIMULUS CONDITIONS

	Prime	Target	No. Trials
Automatic block			
Related word	DOCTOR	NURSE	30
Neutral word		HORSE	30
Unrelated word	TABLE	ANIMAL	120
Unrelated nonword	LARGE	BESKET	30
Neutral nonword		HIMMER	30
		Total	240
Related word	BREAD	BUTTER	120
Neutral word		CHAIR	30
Unrelated word	RIVER	SISTER	30
Unrelated nonword	FLOOR	SEMPLE	30
Neutral nonword		WENDOW	30
		Total	240

reflect the same set of processes up to response selection (McCarthy & Donchin, 1981), it was predicted that RT and P300 latency to target stimuli would reveal a pattern of effects consistent with the Posner and Snyder model.

METHOD

Subjects. Subjects were 24 volunteers (11 male, age range 18 to 36 years). All were paid $10.00 and the subject with the best combination of response speed and accuracy won $50.00.

Apparatus. A Varian computer was used to control the experiment and record all the data. A Burroughs plasma panel was used to display stimuli. Brain waves (EEG) and eye movements were recorded using Grass 7P511 amplifiers (bandpass of 0.1 to 40 Hz).

Stimuli and procedures. Stimuli were three- and six-letter strings. Primes were always words and targets were both words and nonwords. Nonwords were orthographically legal and pronounceable and were derived by replacing one letter near the center of a real word. Half of the nonwords were paired with word primes and the other half were paired with a neutral prime (a blank-see Table 1 for details).

Word targets were selected from a master list of 360 semantically related pairs which were divided into 12 lists of 30 pairs each. Each list was balanced for prime and target length. Across subjects each list (and therefore each word) occurred twice in all of the possible word conditions. However, each subject saw each list only once.

In the automatic block, 12.5% and in the attentional block, 50% of targets were semantically related to the preceding prime (e.g., NURSE-DOCTOR). The balance of each block included trials with targets that were unrelated to the prime and trials with no lexical prime (neutral). Trials with unrelated targets included word-word (e.g., TABLE-ANIMAL) and word-nonword (e.g., LARGE-BESKET) combinations. Neutral trials included blank-word (e.g., -TRUCK) and blank-nonword (e.g., -BERK) combinations. Table 1 lists the five conditions and the number of trials in each for the two blocks of trials.

Each subject participated in two (one automatic and one attentional) blocks of 240 trials. Order of blocks was counterbalanced between subjects (12 subjects per order). There were 40 practice trials prior to the first experimental block.

Each trial consisted of the following sequence of events: (a) a fixation dot in the center of the screen; which was replaced by (b) a prime word surrounded by a border of asterisks or the asterisk border alone (blank or neutral) for 300 msec; (c) a dark field for 850 msec; (d) the target letter string for 300 msec; (e) a 2-sec response interval; and (f) the return to the fixation point. The next trial began approximately 3 sec later after the computer determined that all eye movement and EEG artifact had dropped below a criterion level.

Ag/AgCI electrodes were attached at Oz (midline occipital), RP (right parietal-P3 in International 10/20 system nomenclature), LP (left parietal or P4 site), Fz (midline frontal), and referenced to linked earlobes (Al and A2). Electrodes were also placed at right and left temporoparietal locations (RTP and LTP) approximately 3 cm behind the top of each ear. An electrode for monitoring eye artifact was positioned below and to the left of the eye. All electrode impedances were less than 5 kohms.

Data reduction and analysis. The six channels of EEG and one channel of eye movement data were digitized at the rate of 200 samples/sec for a total of 2.4 sec starting 50 msec pre-prime and continuing until 1200 msec post-target onset. Only trials free of eye and EEG artifact (as determined by computer) were included in each average. Trials where the subject did not make a behavioral response within 2 sec or made a wrong response were also not included in average ERPs. Sixty average ERPs were formed per subject (2 blocks x 5 trial types x 6 electrode sites).

The approach to data analysis involved the use of repeated-measures ANOVAs (BMDP2V) followed, in cases where specific predictions were made, by planned comparisons. All treatment effects with greater than 1 *df* were evaluated using the Geiser-Greenhouse (1959) procedure.

For ERPs the dependent measures were amplitudes and latencies of components identified in prime and target waveforms. The behavioral measures were reaction time and percentage errors. Separate analyses were performed on the data from prime and target stimuli, and within targets only words were analyzed because of the different probabilities of words and nonwords. Depending on the analysis, factors included block (automatic vs. attentional), electrode site (Oz vs. Fz vs. RP vs. LP vs. RTP vs. LTP), and trial type. The trial type factor consisted of comparisons of related, unrelated, and neutral conditions for analyses involving target words and word and blank conditions for analyses involving primes. Because most of the predictions made for target measures involved specific contrasts between the neutral and related and the neutral and unrelated conditions separate planned comparisons were made for each.

RESULTS

Figure 1 contains plots of the grand mean composite ERPs (prime and target together) for each electrode site for the automatic and attentional blocks. The most notable features in these waveforms were a moderate amplitude positive peak between 200 and 250 msec (prime P200), a negative

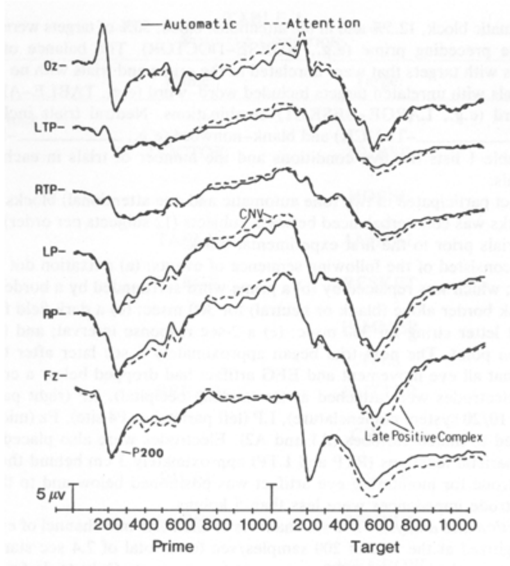

FIG. 1. Grand mean ERPs averaged across the five different trial types for primes and targets together (composite). The solid line is from the automatic session and the dashed line is from the attentional session. Time is in milliseconds. Prime stimulus onset is marked by the left most vertical calibration bar on the time scale and target onset is marked by the calibration bar in the center of the time scale. In this and all subsequent figures positive polarity is.plotted in the downward direction. Prime P200, prime-target CNV, and the target late positive complex are all labeled on this figure. Oz, occipital midline; LTP, left temporoparietal; RTP, right temporoparietal; LP, left parietal; RP, right parietal; Fz, frontal midline.

shift (contingent negative variation-CNV) between 750 and 1150 msec, and a large positive complex peaking at 575 msec post-target onset. There was a high degree of interhemispheric symmetry in the overall ERPs, although at the parietal sites the right hemisphere target ERP tended to have a more positive late positive complex.

ERPs to primes. None of the prime ERPs in this study revealed a large P300 (Fig. 1). However, there was more positive activity in the latency range typically ascribed to P300 (300 and 650 msec) in the attentional block compared to the automatic block (Fig. 1). To examine the reliability of this difference the mean amplitude in the range of 300 to 650 msec was calculated for each prime. Attentional block primes were significantly more positive in this area than were primes from the automatic block (Table 2). A significant electrode site effect indicated that this component

TABLE 2 ANOVA
RESULTS

Analysis	Effect[a]	F	*df*	*p*[b]
Prime P3 amplitude	block	4.12	1,23	.05
	es	6.37	5,115	.003
Prime CNV area	block	4.20	1,23	.05
Target area	block	5.81	1,23	.02
200-525 msec	It	3.84	2,46	.03
Words	block x tt	19.70	2,46	.0001
	es	27.16	5,115	.0001
Target area	block	18.37	1,23	.0003
525-1100 msec	block x It	9.83	2,46	.03
Words	es	18.99	5,115	.0001
RT	tt	78.6	2,46	.0001
Words	block x It	22.21	2,46	.0001
Errors	tt	6.53	2,46	.004
Words	block x It	14.95	2,46	.0001
Target P3	block	4.37	1,23	.05
Latency	tt	50.10	2,46	.0001
Words	es	5.28	5,115	.002
	block x It	9.15	2,46	.0001

[a]tt, trial type (related vs. neutral vs. unrelated or word vs. blank); block, automatic vs. attentional; es, electrode site (Oz vs. LTP vs. RTP vs. LP vs. RP vs. Fz).
[b] All p values reflect Giesser-Greenhouse corrections.

had a scalp distribution much like the traditional P300 (parietal maximumTable 3).

Activity at the end of the prime ERP epoch (750 to 1150 msec) was also measured to determine if the late negative wave seen in Fig. 1 (CNV) would differentiate the automatic from attentional ERPs (Table

TABLE 3

MEAN PRIME ERP AREA MEASURES[a]

	Oz	LTP	RTP	LP	RP	Fz
P300						
Automatic	1.0(2.5)	1.4(1.3)	1.8(1.1)	2.5(2.0)	2.7(2.2)	3.0(3.4)
Attentional	1.6(2.4)	1.7(1.4)	2.1(1.2)	3.0(2.1)	3.3(2.6)	3.4(3.5)
CNV						
Automatic	0.6(2.5)	-.5(1.5)	-.6(1.8)	-1.2(2.7)	-1.3(3.2)	1.5(4.5)
Attentional	0.1(3.0)	-.9(1.5)	-.8(1.7)	-2.0(2.9)	-2.1(3.4)	1.1(4.0)

[a]scores are in microvolts.

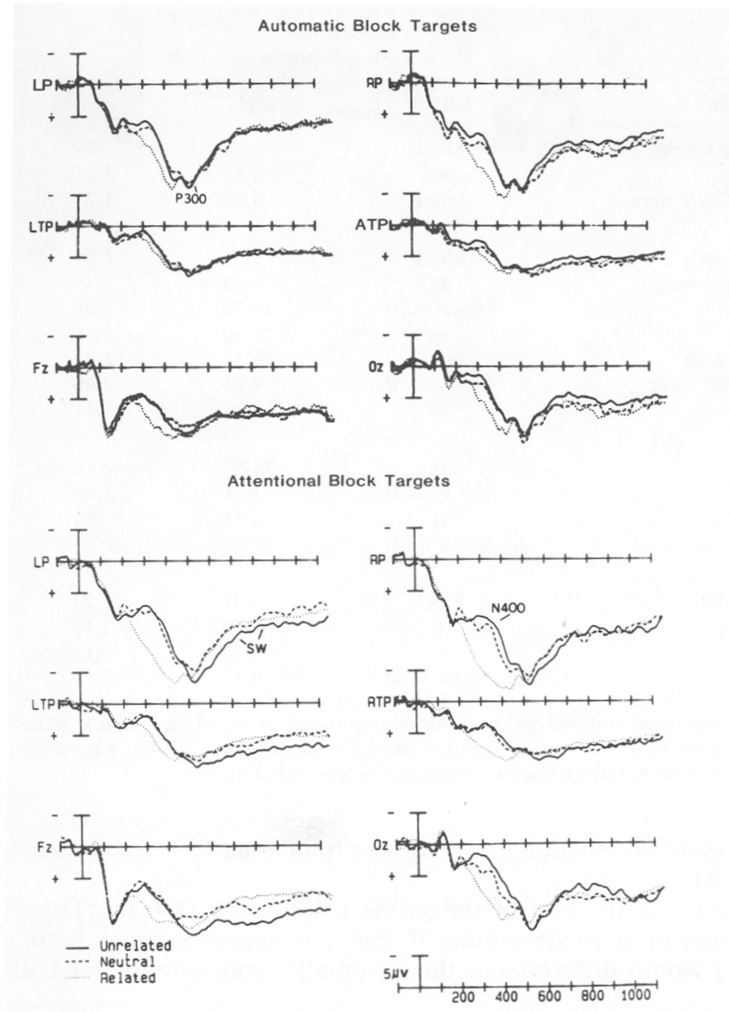

FIG. 2. Target word ERPs: Time is in milliseconds, stimulus onset is the calibration bar.

3). Only the parietal sites revealed a significant effect of blocks. The attentional block had a larger (more negative) CNV than the automatic block. At the parietal sites CNV was larger on the right side of the head.

ERPs to targets. Plotted in Fig. 2 are the ERPs to the three types of target words in each block of trials. In both blocks the primary difference between the three target conditions was that neutral and unrelated targets were more negative than related targets between 200 and 500 msec.

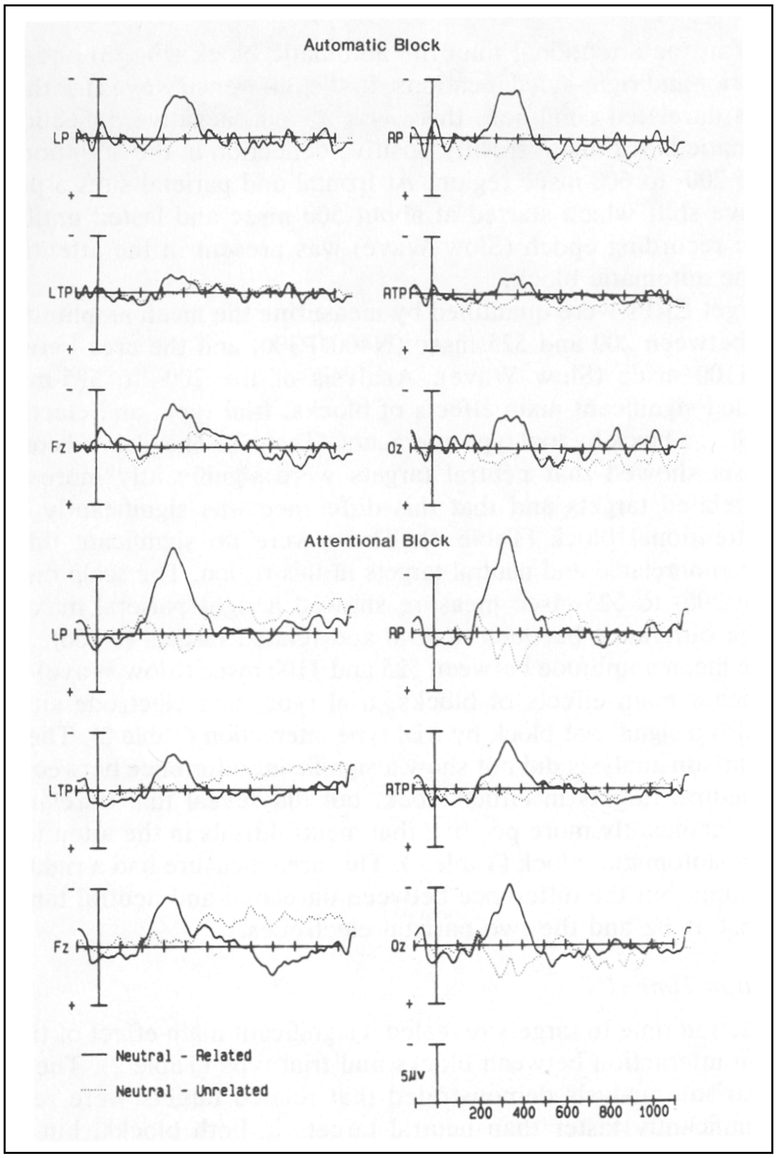

FIG. 3. Target difference waveforms: Time is in milliseconds, stimulus onset is the calibration bar.

To help better visualize the differences between the ERPs in the three target conditions "difference waves" were formed for each subject in each block by subtracting related target ERPs from neutral target ERPs and unrelated target ERPs from neutral target ERPs (Fig. 3). The resulting waveforms revealed a large negative deflection peaking at 400 msec (N400) for neutral minus related ERPs. This N400 effect appeared to be larger in the attentional than the automatic block (Fig. 3) and larger at posterior and right-sided locations. In the difference waves for the neutral minus unrelated condition, there was a small negative deflection in the automatic block and a slightly positive deflection in the attentional block in the 200- to 600-msec region. At frontal and parietal sites a prolonged positive shift which started at about 500 msec and lasted until the end of the recording epoch (Slow Wave) was present in the attentional but not the automatic block.

Target ERPs were quantified by measuring the mean amplitude for the area between 200 and 525 msec (N400/P300) and the area between 525 and 1100 msec (Slow Wave). Analysis of the 200- to 525-msec area revealed significant main effects of blocks, trial type, and electrode site as well as a block by trial type interaction (Table 2). The planned comparison analysis showed that neutral targets were significantly more negative than related targets and that this difference was significantly larger in the attentional block (Table 4). There were no significant differences between unrelated and neutral targets in this region. The scalp distribution of the 200- to 525-msec measure showed a right parietal maximum as did the difference between neutral and related targets (N400).

The mean amplitude between 525 and 1100 msec (Slow Wave) revealed significant main effects of blocks, trial type, and electrode site. There was also a significant block by trial type interaction (Table 2). The planned comparison analysis did not show a significant difference between related and neutral targets in either block, but did reveal that unrelated trials were significantly more positive than neutral trials in the attentional, but not the automatic, block (Table 4). This area measure had a right parietal maximum, but the difference between unrelated and neutral targets was greatest at Fz and the two parietal electrodes.[1]

Reaction Time (RT)

Reaction time to targets revealed a significant main effect of trial type, and an interaction between blocks and trial type (Table 2). The planned comparison analysis demonstrated that related targets were responded to significantly faster than neutral targets in both blocks, but that the difference was significantly greater in the attentional block (Table 5). The planned comparisons between unrelated and neutral targets did not

[1]A covariance matrix Principal Components Analysis with Varimax rotation was performed on the ERPs from this study to help corroborate the findings from the mean amplitude analyses. Six components (79% of the variance), three responsive to activity in the prime epoch and three responsive to activity in the target epoch, were extracted. Two of the prime PCA components produced the same pattern of effects and were maximally loaded in the same time band as the area measures for P300 and CNV. Two of the target PCA components produced the same pattern of effects and were maximally loaded in the same time band as the early (200 to 525 msec) and late (525 to 1100 msec) target area measures.

TABLE 4 MEAN (STANDARD DEVIATION) ERP AREA BETWEEN 200 AND 525 msec AND BETWEEN 525 AND 1100 msec FOR ALL ELECTRODE SITES[a]

	Oz	LTP	RTP	LP	RP	Fz
			200 to 525 msec (N400/P300)			
Automatic block						
Related	7.0(3.0)	2.6(1.2)	3.5(2.1)	8.3(3.6)	9.8(3.9)	4.2(2.8)
Neutral	5.4(2.8)	2.5(1.1)	2.9(1.6)	7.2(4.1)	8.2(3.9)	3.0(2.5)
Unrelated	5.6(3.2)	2.4(1.4)	3.6(2.3)	7.5(4.3)	8.7(4.1)	3.6(2.6)
Attentional block						
Related	8.4(3.2)	4.3(2.1)	5.5(3.6)	11.2(5.1)	13.1(5.6)	6.0(3.4)
Neutral	6.9(3.1)	2.8(1.8)	3.1(1.9)	7.6(4.5)	8.7(4.6)	2.9(1.6)
Unrelated	6.4(3.3)	2.8(2.2)	3.6(2.2)	7.7(4.8)	9.4(4.9)	4.2(2.2)
			525 to 1100 msec (Slow Wave)			
Automatic block						
Related	2.8(2.3)	1.9(1.7)	2.5(1.5)	3.3(2.3)	4.4(2.8)	2.9(2.6)
Neutral	2.8(2.0)	1.9(1.8)	2.6(1.5)	3.5(2.3)	4.6(2.6)	3.0(2.5)
Unrelated	2.3(1.8)	2.0(1.6)	2.2(1.2)	3.4(2.3)	4.0(2.4)	3.1(2.3)
Attentional block						
Related	3.5(1.9)	2.4(1.2)	2.7(1.1)	4.2(1.9)	5.0(2.1)	3.4(2.2)
Neutral	3.7(1.8)	2.5(7.3)	3.0(1.3)	4.0(2.1)	5.0(2.4)	3.6(2.2)
Unrelated	3.4(2.5)	3.1(1.7)	3.1(1.2)	4.8(2.7)	5.8(3.0)	4.6(2.3)

[a]Scores are in microvolts.

TABLE 5

MEAN (STANDARD DEVIATION) RT, PERCENTAGE ERRORS, AND P300 LATENCY

	Related	Neutral	Unrelated
	Reaction Time		
Automatic	493(58)	558(77)	528(60)
Attentional	459(50)	553 (75)	553(79)
	Percentage errors		
Automatic	.82(1.45)	1.38(2.6)	1.45(1.5)
Attentional	.55(1.6)	1.93(2.75)	2.21(2.6)
	P300 Latency (parietal sites)		
Automatic	512(65)	558(65)	545(58)
Attentional	508(82)	564(70)	583(59)

reveal a significant difference in the predicted direction (i.e., unrelated targets were responded to as fast or faster than neutrals), however, the block by trial type interaction indicated that while subjects responded at about the same speed to targets following neutral primes in both blocks that they were significantly slower to unrelated targets in the attentional block.

Target P300 Latency

Analysis of the latency of the most positive peak in target ERPs between 250 and 700 msec (P300) revealed a significant main effect for trial type and a significant interaction between blocks and trial type (Table 5). The planned comparison analysis revealed that related targets had a significantly shorter latency P300 than neutral targets, although, there was no difference between the automatic and attentional blocks. A trial type by block interaction in the planned contrasts between unrelated and neutral targets indicated that there was an increase in the latency of the P300 peak going from the automatic to the attentional block in the unrelated condition (Table 5).

Error Data

The overall error rate was 4.33%. Because the distribution of errors was skewed toward low percentages these data were transformed using an arc sine function prior to analysis (Myers, 1979). There was a significant main effect of trial type and a significant interaction between trial type and block (Table 2). The planned comparison analysis revealed that subjects made significantly fewer errors on related than on neutral trials, particularly in the attentional block. In the planned comparisons between neutral and unrelated trials a significant trial type by block interaction indicated that although errors increased for both trial types in the attentional block, the trend was more pronounced for unrelated trials.

DISCUSSION

The event-related potentials in this study produced a number of interesting findings. Inducing subjects to either ignore or attend to the semantic relationship between the prime and target stimuli resulted in ERP differences to the primes, even though no overt behavioral response was required to the primes themselves. There were also differences in ERPs to targets. Comparisons between words which followed semantically related and neutral primes demonstrated significant differences both under conditions where primes were processed automatically and using attentional resources, although the differences were greater in the attentional condition. Similar comparisons between words which followed semantically unrelated and neutral primes did not reveal a difference in the automatic condition, but did show late ERP differences in the block of trials where attentional resources were directed to the prime-target relationship. In general, the behavioral results were in agreement with the ERP findings, although only errors showed a difference between neutral and unrelated targets.

As in previous reports (e.g., Neely, 1977; den Heyer et al., 1983) indirect evidence based on measures of target processing (RT, errors, target P300 latency) suggested that subjects in the current study were able to comply with instructions to either ignore or attend to the relationship between primes and targets. However, this is the first study to report direct evidence of differences in the processing of passively read primes. In the ERPs recorded to the primes themselves there was a significant difference between the automatic and attentional blocks in the amplitude of a positivity between 200 and 600 msec (P300) and a negativity between 600 and 1125 msec (CNV). Both of these components were larger in the attentional than the automatic block (Fig. 1).

The findings on P300s to primes are consistent with the results of a number of other studies which have shown that P300 is sensitive to attentional manipulations. For example, in studies of mental workload (e.g., Isreal, Chesney, Wickens, & Donchin, 1980) it has been demonstrated that P300 amplitude is sensitive to the allocation of processing resources within a dual-task environment. Stimuli designated through instructions as being part of a primary task produce larger P300s than do stimuli associated with the secondary task (Isreal et al., 1980). Although in the current study subjects were not instructed that attention to the primetarget relationship was their primary task (this was in fact a secondary task), they were told that the relationship would aid performance in the primary task. Kramer, Wickens, and Donchin (1985) have shown that the existence of a relationship between primary and secondary task stimuli which aids primary task performance (dual-task integrality) results in larger P300s to the secondary task stimuli.

A number of studies have shown that the amplitude of a slow negative potential (CNV) that arises during the warned foreperiod of a choice RT task is sensitive to the parameters which define the relationship between pairs of stimuli (e.g., Walter, Cooper, Aldridge, McCallum, & Winter, 1964). If there is no apparent relationship then the CNV is usually small, but if there is a reliable or predictive relationship that the subject actively attends to then the CNV is usually large (see McCallum, 1979). In the current study primes from both blocks of trials resulted in a CNV waveform (Fig. 1), probably because a response was required to all targets following all primes in both blocks. However, only in the attentional block were subjects instructed to use information available in each prime to make a prediction about targets. The greater CNV amplitudes to primes in the attentional condition of this study are further direct evidence that subjects differentially attended to the prime target relationship in the two blocks of trials.

The target ERP effects in this study clearly resulted from the interaction of several temporally overlapping components. Figure 2 indicates that the P300 was the largest and most distinguishable of these components, while two others which rode in the same time period, but which were partially masked by P300, changed their contribution to the scalp recorded ERP as a function of the prime-target relationship and the mode (automatic or attentional) of prime processing.

The difference waves (Fig. 3) and previous work by others (e.g., Bentin et al., 1985) suggest that the priming effects observed relatively early in target ERPs (250 to 500 msec) were at least partially modulated by the presence or absence of a pre-P300 negativity which was smallest in the related condition of both blocks and largest in the unrelated condition of the attentional block. The scalp distribution (right parietal maximum) and sensitivity of this component to semantic manipulations suggest that it is a member of the N400 family of negativities which have been demonstrated to be sensitive to the degree of semantic expectedness of a lexical event (e.g., Kutas & Hillyard, 1980; Fischler, Bloom, Childers, Rousos, & Perry, 1984).

The occurrence of a larger N400 effect in the attentional than in the automatic block is not consistent with the proposal that this component reflects purely automatic semantic priming. If N400 is only sensitive to automatic lexical effects then it should have been of roughly equal amplitude in the two blocks because automatic priming is not thought to be enhanced by increases in the proportion of related pairs (Posner & Snyder 1975b; den Heyer et al., 1983; den Heyer, 1986). However, while it is clear that the N400 effect was enhanced by the attentional manipulation in this task (Fig. 3), it does not appear that attentional processes are a necessary ingredient for generating an N400 as both the automatic block of this study and the short SOA condition in the Boddy (1986) experiment (discussed in the Introduction) produced substantial negativities in the 400-msec time range.

Figures 2 and 3 suggest that effects late in the target ERP epoch were modulated in part by a post-P300 positivity that was largest on unrelated trials and was smallest on related trials in the attention block. Ruchkin et al. (1980a, 1980b) reported that an ERP component, which they referred to as Slow Wave, was sensitive to the difficulty and/or the duration of decisional processes. If the post-P300 positivity in the current study is related to Ruchkin et al.'s Slow Wave then increases in the amplitude of this component or at least greater dissociation from P300 should have been most evident on trials with the most difficult or time-consuming processing requirements. This should have been unrelated targets in the attention block because subjects were supposedly actively anticipating related pairs of stimuli. Under these conditions the occasional occurrence of an unrelated pair is thought to require an effortful shift (at some level in the processing system) to information about the unanticipated target. A late target positivity between 525 and 1100 msec proved to be sensitive to such a Slow Wave-like effect (i.e., unrelated words in the attention block were more positive than any other word condition).

It is interesting that in a PCA performed on these data that a component which proved sensitive to this same effect reached its peak latency approximately 150 msec later than the mean RT latency for words, suggesting that this positivity reflects the activity of a relatively slow process that occurs too late to significantly effect subjects' behavioral responses during speeded lexical decision. The important message in this finding is that just because the behavioral response in a task does not prove sensitive (or proves to be only marginally sensitive) to task manipulations, this cannot be taken as conclusive evidence that there was no impact on the processing system (West and Stanovich, 1982).

Recently it has been suggested that not all of the behavioral effects found in the lexical decision task are due to processes occurring prior to or during lexical access and that one or more postlexical processes play a significant role in lexical decisions (e.g., Seidenberg, Waters, Sanders, & Langer, 1984; Balota & Chumbley, 1984). Seidenberg et al. (1984) have argued that the attentional effects due to manipulations of the proportion of related pairs which occur in lexical decision are postlexical because similar effects are not seen in pronunciation tasks which they assert only tap pre- and interlexical processes (in their experiments there were no increases in facilitation or interference in naming latencies as the proportion of related pairs increased, but there were in lexical decision). The implication here is that lexical operations occur within an encapsulated module that can not be penetrated by higher level processes such as conscious attention (Forster, 1979; Fodor, 1983). There are those who have suggested that higher level contextual processes play a direct role in lexical operations (e.g., McClelland & Rumelhart, 1981; Marslen-Willson & Tyler, 1980).

Although the ERP technique may eventually help determine whether lexical access is an autonomous operation, data from the current study are somewhat equivocal on this point. This is not surprising given that the purpose of this study was not to isolate the locus of the various priming mechanisms. However, the long latency of the Slow Wave effect, which produced the only difference between unrelated and neutral words, would appear to be too late to reflect a pre- or interlexical operation, and thus probably was sensitive only to postlexical processes. However, the N400 effect (difference between neutral and related targets) which had a relatively early onset in both blocks appears to be somewhat earlier in the attentional than the automatic block. As can be seen in Fig. 3 the attentional block right parietal difference wave crossed the zero baseline at 180 msec and was clearly negative at 210 msec, while the automatic block difference wave crossed baseline at 210 msec and did not go substantially negative until 270 msec. Although any firm conclusion must await a more controlled chronometric study of the N400 onset times these data do suggest that paying attention to the meaning of the prime enhanced some aspect of the encoding operations performed on the related targets.

The latency of the P300 peak and RT was earlier to related targets than neutral targets in both blocks. However, unlike RT, P300 latency did not show an additional difference between related and neutral stimuli due to the attentional manipulation. On the other hand P300 latency, but not RT, had a significantly longer latency to unrelated than neutral targets in the attentional block.

There are a number of factors that should be considered in interpreting these P300 and RT effects. First, although the RT interference effect was not significant, the effect was significant for errors, suggesting that subjects may have traded some accuracy in the attentional block unrelated condition for faster responses (Pachella, 1974). Second, as pointed out in the Introduction, it is noteworthy that several studies using the lexical decision task have failed to demonstrate a robust difference in RT between neutral and unrelated stimuli (interference), in the presence of a large difference between related and neutral stimuli (facilitation). One possibility for the lack of either or both effects may have to do with the selection of the neutral stimulus. Because the neutral condition is the baseline from which facilitation and interference are determined any facilitation or interference due to the neutral itself will result in an over- or underestimation of these effects. Several studies have now reported such effects on RT (deGroot, Thomassen, & Hudson, 1982; McDonald & Schvanveldt, 1982; Jonides & Mack, 1984) and P300 latency (Duncan-Johnson & Donchin, 1982). For example, deGroot et al. (1982) showed that a nonlexical neutral prime (the letter string "XXXX") slowed target RT in comparison to a lexical neutral prime (the word "ready") and concluded that studies using nonlexical neutral primes may tend to overestimate facilitation effects and underestimate interference effects. The use of a nonlexical prime in the current study may have contributed to the lack of a significant RT interference effect, although the ERP Slow Wave data suggest that subjects' responses were probably too fast for attentional interference to have built up to an appreciable level.

Another factor that should be considered in considering the chronometric measures of this study, one specific to the P300 latency results, has to do with the effect of overlapping waveforms on the latency of scalp recorded ERP components. It is well known that changes in the amplitude of one or both of two overlapping components can affect the apparent point in time at which the peak of either component occurs (e.g., Donchin & Heffley, 1979). In the current study P300 latency measurements may have been compromised by the overlapping N400 and Slow Wave components. On related trials N400 was small or absent and thus did not obscure the early phase of P300 activity, therefore P300 appeared to have a relatively short latency peak. However, on unrelated trials early P300 activity may have been obscured (clipped) by the large overlapping N400, and late P300 activity may have been enhanced by the overlapping Slow Wave, resulting in a later apparent P300 peak latency. The point is that the absolute latency of the peak of the P300 may, in this task, be less important than the time course of the interaction between the N400, P300, and Slow Wave. These data suggest that caution should be used in interpreting latency effects in any study where conditions of the experiment may differentially influence the amplitude of overlapping components.

In summary, the Posner and Snyder (1975a, 1975b) model as applied to linguistic processes received further support from both the ERP and behavioral findings of this study. ERPs to primes demonstrated that subjects differentially processed these stimuli under conditions designed to induce either automatic or attentional processing. In ERPs to targets both the N400 and Slow Wave components proved to be differentially sensitive to the semantic relationship between primes and targets and the manner in which primes were processed.

REFERENCES

Balota, D. A., & Chumbley, J. 1. 1984. Are lexical decisions a good measure of lexical access? The role of word frequency in the neglected decision stage. Journal *of Ex*perimental Psychology: Human Perception and Performance, 10, 340-357.

Becker, C. A. 1980. Semantic context effects in visual word recognition: An analysis of semantic strategies. Memory and Cognition, 8, 493-512.

Bentin, S., McCarthy, G., & Wood, C. 1985. Event-related potentials, lexical decision, and semantic priming. *Electroencephalography and Clinical Neurophysiology, 60, 353-355*

Boddy, J. *1986.* Event-related potentials in chronometric analysis of primed word recognition with different stimulus onset asynchronies. *Psychophysiology, 23, 232-244.* deGroot, A., Thomassen, A., & Hudson, P. *1982.* Associative facilitation of word recognition as measured from a neutral prime. *Memory and Cognition, 10, 358-370.*

den Heyer, K. *1986.* Manipulating attention-induced priming in a lexical decision task by means of repeated prime-target presentations. *Journal of Memory and Language, 25, 19-42.*

den Heyer, K., Briand, K., & Dannenbring, G. *1983.* Strategic factors in a lexical decision task: Evidence for automatic and attention-driven processes. *Memory and Cognition, 11, 374-381.*

Donchin, E. (Ed.). *1984. Cognitive psychophysiology Vol. I.* Hillsdale, NJ: Erlbaum. Donchin, E., & Heffley, E. *1978.* Multivariate analysis of event-related potential data: a tutorial review. In D. Otto (Ed.), *Multidisciplinary perspectives in event-related brain potentials.* Washington, DC: Office of Research and Development. Pp. *555-572.*

Duncan-Johnson, C., & Donchin, E. *1982.* The *P300* component of the event-related brain potential as an index of information processing. *Biological Psychology, 14, 1-52.*

Fischler, I., Bloom, P. A., Childers, D., Roucos, S., & Perry, N. *1983.* Brain potentials related to stages of sentence verification. *Psychophysiology, 20, 400-409.*

Fodor, J. A. *1983. Modularity of mind.* Cambridge, MA: Bradford-MIT press.

Forster, K. I. *1979.* Levels of processing and the structure of the language processor. In W. E. Cooper & E. C. T. Walker (Eds.), *Sentence processing: Psycholinguistic studies presented to Merrill Garrett.* Cambridge, MA: MIT Press.

Geisser, S., & Greenhouse, S. W. *1959.* On methods in the analysis of profile data. *Psychometrica, 24, 95-112.*

Holcomb, P. J., Dykman, R. A., Oglesby, D. M., & Johnston, V. S. *1982.* ERP related differences in mental ability. *Psychophysiology, 19, 324.*

Isreal, J. B., Chesney, G. L., Wickens, C. D., & Donchin, E. *1980. P300* and tracking difficulty: Evidence for multiple resources in dual-task performance. *Psychophysiology, 17, 259-273.*

Jonides, J., & Mack, R. *1984.* On the cost and benefit of cost and benefit. *Psychological Bulletin, 96, 29-44.*

Kramer, A., Wickens, D., & Donchin, E. *1985.* Processing of stimulus properties: Evidence for dual-task integrality. *Journal of Experimental Psychology: Human Perception and Performance, 11, 393-408.*

Kutas, M., & Hillyard, S. A. *1980.* Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science, 207, 203-205.*

Kutas, M. Lindamood, T. E., & Hillyard, S. A. *1985.* Word expectancy and event-related brain potentials during sentence processing. In S. Kornblum and J. Requin (Eds.), *Preparatory states and processes.* Hillsdale, NJ: Erlbaum.

Marslen-Willson, W., Tyler, L. K. *1980.* The temporal structure of spoken language. *Cognition, 8, 1-71.*

McCallum, W. *C. 1979.* Cognitive aspects of slow potential changes. In J. E. Desmedt (Ed.), *Cognitive components in cerebral event-related potentials and selective attention, progress in clinical neurophysiology, Vol. 6.* New York: Karger.

McCarthy, G., & Donchin, E. *1981.* A metric for thought: A comparison of *P300* latency and reaction time. *Science, 211, 77-80.*

McClelland, J., & Rumelhart, D. *1981.* An interactive activation model of context effects in letter perception: Part 1. An account of basic findings. *Psychological Review, 88, 375-407.*

McDonald, J. E., & Schvaneveldt, R. 1982. *Non-semantic priming in word recognition*. Unpublished manuscript.

Myers, J. L. 1979. *Fundamentals of experimental design*. Boston: Allyn & Bacon.

Neely, J. 1976. Semantic priming and retrieval from lexical memory: Evidence for facilitory and inhibitory processes. *Memory and Cognition, 4,* 648-654.

Neely, J. 1977. Semantic priming and retrieval from lexical memory: Role of inhibitionless spreading activation and limited-capacity attention. *Journal of Experimental Psychology: General, 106,* 226-254.

Paap, K., & Ogden, W. 1981. Letter encoding in an obligatory but capacity-demanding operation. *Journal of Experimental Psychology: Human Perception and Performance,* 7, 518-527.

Pachella, R. G. 1974. The interpretation of reaction time in information processing research. In B. H. Kantowitz (Ed.), *Human information processing: Tutorials in performance and cognition*. Hillsdale, NJ: Erlbaum.

Posner, M., & Snyder, C. R. R. 1975a. Attention and cognitive control. In R. L. Solso (Ed.), *Information processing and cognition: The Loyola symposium*. Hillsdale, NJ: Erlbaum.

Posner, M., & Snyder, C. R. R. 1975b. Facilitation and inhibition in the processing of signals. In P. M. A. Rabbitt and S. Dornic (Eds.), *Attention and performance V*. New York: Academic Press.

Pritchard, W. S. 1981. Psychophysiology of P300. *Psychological Bulletin, 89,* 506-540.

Regan, D. (in press). *Evoked potentials in psychology, sensory physiology and clinical medicine*. New York: Wiley.

Ruchkin, D. S., Sutton, S., Kietzman, M. L., & Silver, H. 1980a. Slow wave and P300 in signal detection. *Electroencephalography and Clinical Neurophysiology, 50,* 35-47. Ruchkin, D. S., Sutton, S., & Stega, M. 1980b. Emitted P300 and slow wave event-related potentials in guessing and detection tasks. *Electroencephalography and Clinical Neurophysiology, 49,* 1-14.

Rugg, M. 1984. Event-related potentials and the phonological processing of words and non-words. *Neuropsychologia, 22,* 435-443.

Rugg, M. 1985. The effects of semantic priming and word repetition on event-related potentials. *Psychophysiology, 22,* 642-647.

Seidenberg, M., Waters, G., Sanders, M., & Langer, P. 1984. Pre- and postlexical loci of contextual effects on word recognition. *Memory and Cognition, 12,* 315-327.

Taylor, D. A. 1977. Time course of context effects. *Journal of Experimental Psychology: General, 106,* 404-426.

Tweedy, J. R., Lapinski, R. H., & Schvaneveldt, R. W. 1977. Semantic-context effects on word recognition: Influence of varying the properties of items presented in an appropriate context. *Memory and Cognition, 5,* 84-89.

Walter, W. G., Cooper, R., Aldridge, V. J., McCallum, W. C., & Winter, A. L. 1964. Contingent negative variation: An electric sign of sensorimotor association and expectancy in the human brain. *Nature (London), 203,* 380-384.

West, R. F., & Stanovich, K. 1982. Source of inhibition in experiments on the effect of sentence context on word recognition. *Journal of Experimental Psychology: Learning, Memory and Cognition, 8,* 385-399.