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**THOUGHT AND ACTION:
EVENT-RELATED POTENTIALS AND BEHAVIOUR
IN A PRIMED AND SPEEDED LEXICAL DECISION TASK**

by

Blanche Conder

A thesis submitted to the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the degree

Master of Arts

School of Psychology

University of Ottawa

December 1993



Blanche Conder, Ottawa, Canada, 1993



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ABSTRACT

To examine the relation between cognitive and response processes, event-related potentials (ERPs) were recorded from 10 subjects during semantically primed lexical decisions in an Accuracy condition (response deadline 700 msec) and a Speed condition (deadline 450 msec). Targets were the prime's antonym, an unrelated word, or a nonword. The Speed condition reduced response time (RT) and accuracy, but not the latency of ERP deflections. RT varied with the amplitude of negativity 250-450 msec only for semantically primed targets. RT was dissociated from the N400 deflection elicited by unrelated and nonword targets. Individual differences in task performance and ERPs suggested that the most accurate subjects favoured early motor inhibition and data-driven processing, whereas slightly faster but significantly less accurate subjects relied on resource-driven processing. Regardless of RT condition, individual differences in processing, and positive response priming, the probability of correctly rejecting a nonword began to rise monotonically after the N400 peak and approached .90 before the peak of the late positive complex. Continuous transmission of response selection information to motor processes before stimulus evaluation processes have been completed is consistent with a parallel distribution of word recognition and response production processes.

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INTRODUCTION

If cognitive psychologists found themselves restricted to a single experimental measure, their measure of choice might well be the time taken to perform a mental task. Response time functions as a workhorse in the construction and testing of theories and models of human information processing. Over the years, one good workhorse can build several models. In an additive model (eg Sternberg, 1969), information processing consists of discrete, sequential stages of processing, the last of which is response production. This model differs from a parallel processes model (eg McClelland, 1979) which proposes that response production begins before stimulus evaluation has been completed. A stochastic model (eg Ratcliff, 1988) attributes decreasing response accuracy as responses become faster to insufficient information accumulation at the moment of response execution. When these models are tested by gradually and systematically speeding responses, the changes in response accuracy support all three types of model, albeit with task specificity (Meyer, Irwin, Osman & Kounios, 1988). Trade-offs between response speed and accuracy in recognition memory tasks, for example, indicate that item recognition involves fast parallel processes, whereas judgments of order recency elicit a slow serial process (McElree & Doshier, 1993).

This project pursues the relation between thought and action in a speeded lexical decision task. Fluctuations in the scalp-recorded brain potential are used as a measure of changes in neural activity generated by information processing, and behavioural responses are considered output. The event-related potential (ERP) is an appropriate complement to behavioural data because the ERP is relatively unaffected by response activation (Duncan-Johnson & Kopell, 1981; Magliero, Bashore, Coles, & Donchin, 1984; McCarthy & Donchin, 1981; Polich & Donchin, 1988; Ragot, 1984). Note that the ERP is a continuous measure of volume conduction beginning before stimulus presentation and continuing past response execution, whereas the overt response is a discrete event.

In a lexical decision task, subjects usually key press to indicate whether or not a string of letters forms a word. When lexical decisions are systematically speeded, the monotonicity of decreasing response accuracy as guessing time decreases indicates that responses are activated by partial information (Experiment 5, Meyer et al, 1988). Evidence of partial information transmission is important because it suggests a continuous flow of information to motor processes, rather than discrete stages of processing. It is not clear, however, whether word recognition processes accelerate as subjects make faster and faster responses, or whether only response processes accelerate. Behavioural data do not reveal whether attention to fast response production affects processes such as semantic retrieval, or whether fast response execution merely interrupts word processing before information accumulation is complete. To monitor covert cognitive activity as overt responses become faster requires a continuous measure of central processing activity, in

addition to the output measure that is being manipulated.

Unlike response speeding which affects response time (RT) directly, the semantic context in which a word is processed appears to affect recognition processes and therefore RT. Reading "cat" and then "dog", for example, facilitates a lexical decision about "dog". To explain the semantic priming effect, the automatic spreading activation theory proposes that neural activation generated by the semantic processing of a priming stimulus ("cat") spreads through nodes of a semantic network. This neural activation automatically facilitates the processing of a semantically related word ("dog") presented just after the prime (Meyer & Schavaneveldt, 1971). The semantic context may also elicit consciously controlled processes (Posner & Snyder, 1975). If subjects can predict that the target will be a specific word, such as the prime's antonym, RT is faster than if subjects expect the target to be any one of several words associated with the prime (Becker, 1980). An expectancy strategy may also delay the response for a word unrelated to the primed semantic category, because a semantic mismatch process after lexical identification delays response execution (Neely, Keefe & Ross, 1989). The effects of semantic context on lexical decisions have generally been inferred from RT variability when subjects are allowed sufficient time to maintain near perfect response accuracy. Under speeded conditions, reduced accuracy and individual differences in the trade-off between response speed and accuracy are to be expected. The accuracy reduction for antonymically primed targets, however, should be relatively small because of the facilitation provided by automatic processes and target predictability.

To elaborate the relation between word recognition processes and response

behaviour, ERPs and behavioural data were examined when the semantic context and the response deadline for a lexical decision were manipulated. While the independent variables were expected to have significant effects on the behavioural response, changes in the ERP as RT varied were expected to be subtle. A separate averaging of single trials was therefore carried out to compare ERPs according to RT bins. The variability of at least two late ERP deflections and their relation to task performance had implications for cognitive theories and models.

A negative ERP deflection peaking about 400 msec after stimulus presentation has been associated with semantic processing. Words semantically incongruous with sentence context elicit N400 of large amplitude (Kutas & Hillyard, 1984). During semantically primed lexical decisions, a significantly larger N400 is elicited by targets unrelated to the prime than by targets primed by a semantically related word (Bentin, McCarthy & Wood, 1985; Boddy, 1986; Kutas, 1985). Since N400 amplitude is small when RT is facilitated by semantic priming, RT could be expected to vary with N400 amplitude. Furthermore, if facilitated neural processing of semantically primed targets is automatic (Meyer & Schavaneveldt, 1971), N400 amplitude reduction for primed targets should occur regardless of the response deadline, because automatic processes pertain regardless of a subject's intentions or strategy (Schneider & Shiffrin, 1977).

N400 is followed by a late positive complex (P300, P3) which peaks at about 600 msec for lexical decisions. The latency of this peak is conventionally used to index the duration of stimulus evaluation processes (Coles, Gratton, Bashore, Eriksen, & Donchin, 1985; Gratton, Coles, Sirevaag, Eriksen & Donchin, 1988; Smid, Mulder & Mulder,

1990). When subjects are asked to make lexical decisions as quickly as possible while maintaining accuracy, the latency of the late positive complex does not differ significantly between words and nonwords, despite significantly faster RT for words than nonwords (Campbell, Lefoll & Desrochers, 1990; Polich & Donchin, 1988). Since in both of these studies nonwords were correctly rejected hundreds of milliseconds after the late positive ERP peak, the authors inferred that negative response selection occurred after stimulus evaluation was complete, and that execution of a negative response was delayed by positive response priming. Another recent study, which averaged ERPs according to the peripheral EMG and the scalp-recorded lateralized readiness potential during a feature detection task, found that correct response selection may occur before stimulus evaluation is complete, and that correcting the peripheral response choice before response execution significantly delays the peak of the late positive complex (Smid et al, 1990). These studies implicated but did not quantify response choice bias.

In the present experiment, the semantic context manipulation consisted of three target types (the prime's antonym, words unrelated to the prime, and nonwords) presented with equal probability. Because the positive response option was likely to be correct ($p=2/3$), a global bias favouring the positive response choice was expected (Pachella, Smith & Stanovich, 1978). Given positive response priming, fast guesses were expected to be positive, that is, incorrect for nonwords. For fast correct trials, however, a positive response choice bias would have to be corrected quickly in order to reject nonwords quickly. It seemed likely that when subjects had to select the negative response very quickly, either this process would make the late positive ERP peak significantly later for

nonwords than real words, or nonword responses would be wrong.

The RT manipulation consisted of an Accuracy condition (response deadline 700 msec) and a Speed condition (response deadline 450 msec). If some subjects alter their "processing mode" to accommodate the response deadline (Luce, 1986), processing differences among subjects or between RT conditions should be apparent in the ERPs. Processing differences leading to the same behavioural response should also be apparent from ERPs. Finally, if stimulus evaluation and response production are discrete processing stages (Sternberg, 1969), the probability of overcoming the positive choice bias and correctly rejecting a nonword should suddenly become better than chance when RT is later than the peak of the late positive complex. On the other hand, if partial information is available to motor processes before stimulus evaluation is complete, the probability of correctly rejecting a nonword should gradually increase with RT and be better than chance before the peak of the late positive complex. Evidence of partial information transmission would be consistent with parallel (McClelland, 1979; Seidenberg & McClelland, 1988) and stochastic (Ratcliff, 1988) models of information processing.

METHOD

Subjects: Ten right-handed subjects (aged 20-41 years) participated in the experiment. All subjects were students or lab personnel who reported normal or corrected vision. Five subjects were male, five female. English was the first language of eight subjects. The two subjects whose mother tongue was not English (one French, one Polish) were fully functional in English. Since data from these subjects did not differ from data of the rest of the group, they were included in the experiment.

Stimuli: Four lists of 120 word pairs were created. Each pair of words consisted of a prime and a target. No word was repeated in a list, although a few words appeared in more than one list. The prime was always a word having an antonym (eg DOWN, FAST, BLACK). The target paired with a prime was the prime's antonym (eg DOWN/UP), or an unrelated word (eg FAST/TREE), or a nonword (eg BLACK/ROKE). Target types were equally probable ($p=1/3$) in each list and order of presentation was randomized separately for each list.

Primes and primed targets were selected from a pretest survey in which 25 persons were given a list of words and asked for the opposite of each word. These words included adjectives, adverbs, and prepositions which elicited the cue's antonym (eg

"down"-> "up"), as well as nouns and verbs which elicited the cue's complement (eg "girl"-> "boy"). A cue word that elicited the identical response from 24 subjects was selected as a possible prime. The cue and its agreed opposite formed possible prime-primed target pairs. Words were further selected for high frequency of occurrence in standard English, although the high frequency criterion of at least 30 occurrences per million words (Francis & Kucera, 1982) was somewhat compromised by a limited supply of very common words with an agreed opposite that is also very common. The pretest survey results provided enough high frequency words to supply 82% of the primes and 87% of the primed targets used in the experiment. Some of the pairs agreed by 24/25 pretest respondents included less common words, which were used to complete the final selection of prime-primed target pairs. Each of the four experimental lists contained a few prime-primed target pairs in which a low frequency word was paired with a high frequency word (eg TAME/WILD) or two lower frequency words were paired (eg WINNER/LOSER). To counterbalance primed and unrelated targets for frequency in standard English, approximately 80% of unrelated targets in each experimental list had a frequency of occurrence of more than 30 times per million, and 20% were lower frequency words (eg LAP, NAIL). Unrelated targets were drawn from different parts of speech and paired with a prime without regard to grammatical function. Orthographically legal and pronounceable nonwords (eg FABE) were created by changing one or two letters of a word unrelated to the prime.

Procedure: Stimuli were presented one at a time in upper case letters at the centre of an IBM compatible monitor. The monochrome display was in amber phosphor on a black background. When viewed from a distance of 70 cm, a string of 2-8 letters subtended a visual angle of 0.7° vertically, and depending on the number letters up to 2.6° horizontally. The same four word lists were presented in an Accuracy condition and a Speed condition. A trial began 500 msec after the offset of an orienting asterisk presented at the middle of the screen. A prime then appeared for 200 msec. The time between the offset of the prime and the onset of the target was 700 msec. Target duration served as a window within which the subject was asked to respond. Target duration was 700 msec when a list was presented in the Accuracy condition, and 450 msec when a list was presented in the Speed condition. The subject's task was to press one key if the target was a real word ($p=2/3$), or another key if the target was not a real word ($p=1/3$). Since a pilot study had indicated that the finger of response did not have a significant effect on RT when the first two fingers of the preferred hand rested on the response keys, the index and middle fingers of the right hand were used for real and not real words, respectively. After a trial, RT feedback appeared at the bottom of the screen to inform the subject whether the response had occurred within the required window. "GOOD" appeared if the RT deadline had been met; "FASTER" appeared if the response was slower than the RT deadline. RT feedback was presented 1600 msec after target onset and lasted 200 msec.

The order of testing the four word lists in two RT conditions (8 trial blocks) was randomized with two constraints: (1) The first trial block was run in the Accuracy

condition because only a few practice trials had been held; and (2) the same word list was not presented twice in a row. In all, each subject made 960 lexical decisions (120 targets per list x 4 lists x 2 RT conditions).

ERP Data Collection: The scalp was cleansed and abraded with a sterile needle at electrode sites to remove electrodermal sources of artifact (Picton & Hillyard, 1972). Beckman Ag/AgCl electrodes were then attached with electrode paste at midline frontal (Fz), vertex (Cz), and parietal (Pz) sites. A noncephalic balanced sternovertebral site was used as reference (Stephenson & Gibbs, 1951). The EOG was recorded between the supra- and infra-orbital ridges of the right eye. Interelectrode impedance was less than 2 kOhms. The high filter was set at 35 Hz; the time constant was 2 sec. The EEG was sampled every 10 msec over a total sweep time of 3000 msec, beginning 500 msec before the onset of the prime and continuing for 2500 msec after onset of the prime. Single trials were stored for later off-line averaging. The 2000 msec interval between EEG sweeps allowed RT feedback (200 msec), a blank screen (1600 msec), and the asterisk signaling the next trial (200 msec).

Behavioural Data Reduction: RT was a subject's average median response time. Response choice was used for two calculations: (1) A subject's correct responses for a target type were converted to percentage correct in each trial block. The mean of these percentage scores yielded accuracy rate (%C). Failure to respond counted as an error. (2) The four trial blocks were collapsed in order to estimate a subject's sensitivity (d')

and response choice bias ($\log B$) in each RT condition. The response choice bias statistic took into account the unequal probability of real words and nonwords (Smith, 1974).

ERP Scoring and Analysis: After the rejection of trials with EOG in excess of ± 100 μV , ERP data were averaged off-line in two ways. First, to arrive at composite grand averages, single trials were sorted by subject, trial block, RT condition, target type, and response choice, and averaged by trial block. The four trial blocks per RT condition were then averaged. Eight ERP deflections were scored, separately for each subject, for *average amplitude and peak latency*. The average amplitude of a deflection was the average of all EEG samples within a window capturing a reliable deflection from all subjects. The average amplitude of a deflection following the prime was measured from a baseline computed as the average EEG in the 500 msec before presentation of the prime. The windows for deflections elicited by the prime were N130 (100-150 msec), P235 (150-300 msec), and N400 (300-500 msec). Peak latency was the point of maximum amplitude within the window. Labels were based on the peak latency of the grand average. The beginning of a slow negative shift before target presentation (contingent negative variation, CNV) was scored at the last negative-going crossing of the prestimulus baseline before target presentation at 900 msec. For average CNV amplitude, data points were first averaged in 100 msec segments from 500-900 msec. CNV amplitude was then computed as the average of those segments from the segment capturing CNV onset to the 800-900 msec segment, inclusive.

Because CNV amplitude differed significantly between RT conditions, the average

amplitude of a deflection elicited by the target was measured from a baseline computed as the subject's average EEG amplitude in the 100 msec prior to target presentation. The windows for deflections elicited by the target were N125 (100-150 msec), N270 (240-340 msec), and N400 (350-450 msec). The window for P600 depended on the target type: 400-700 msec for primed words, 500-700 msec for unprimed words, and 500-800 msec for nonwords.

Separate ANOVAs were carried out for the amplitude and latency of each ERP deflection at the electrode of maximum amplitude. The repeated measures factors in these ANOVAs were target type (primed, unprimed, nonword) and RT condition (Accuracy, Speed). The probability of F ratios was adjusted when necessary (Huynh & Feldt, 1970). Paired comparisons were within subjects t-tests (α .05).

The second way of averaging single trials was according to RT. With the four trial blocks of a RT condition collapsed, single trials were sorted into 5 RT bins: RT < 400 msec, RT 400-500 msec, RT 500-600 msec, RT 600-700 msec, and RT > 700 msec. Within a RT bin, data were sorted and averaged, separately for each subject, according to target type, RT condition, and response choice. Ten artifact-free trials per subject were considered a minimum for averaging (Lewis & Ryan-Jones, 1991). A subject's average EEG amplitude in the 100 msec before target presentation served as the baseline from which was computed the average amplitude of two broad deflections elicited by the target. N350 was the average of samples 250-450 msec after target presentation. The windows for average P600 amplitude were the same as for the composite grand averages.

RT bins of 100 msec provided an interval broad enough to accommodate ERP data from several subjects, yet narrow enough to detect significant ERP differences within subjects as RT varied. Even so, some RT bins contained many trials from few subjects, while other bins contained too few trials per subject to permit averaging. Because the subjects in each RT bin varied, statistical analysis was confined to a series of within subjects t-tests. A minimum of 7 subjects was considered necessary to carry out a comparison.

RESULTS

Behavioural Responses. Mean response times and accuracy rates are summarized in Table 1. Correct responses were faster in the Speed condition than the Accuracy condition ($F(1,9)=73.24$, $p < .0001$). The RT for correct trials also varied with the type of target ($F(2,18)=39.03$, $p < .0001$). Correct responses were faster for primed than unrelated targets ($p < .002$, Accuracy condition; $p < .02$, Speed condition), and faster for unrelated words than nonwords ($p < .02$, Accuracy; $p < .0001$, Speed). The RT for correct responses was not significantly affected by interaction of RT condition and target type ($p > .17$).

Table 1. Mean Response Times and Accuracy Rates
(Standard Deviation in brackets) $N=10$

	Mean RT in milliseconds		Mean Accuracy Rate
	Correct	Incorrect	% Correct
Accuracy Condition			
Primed	500 (59)	484 (60)	98.3 (1.5)%
Unrelated	565 (67)	641 (122)	95.7 (4.1)%
Nonwords	628 (83)	533 (87)	82.2 (21.0)%
Speed Condition			
Primed	410 (51)	470 (113)	94.8 (3.1)%
Unrelated	439 (59)	483 (51)	91.4 (5.5)%
Nonwords	538 (57)	415 (57)	57.2 (27.3)%

Figure 1 shows the cumulative probability of a correct response as a function of RT. The probability of responding correctly within the 700 msec deadline was .94 for primed words, .87 for unrelated words, and .73 for nonwords. In the Speed condition, the probability of responding correctly within the 450 msec deadline was .70 for primed words, .58 for unrelated words, and .22 for nonwords.

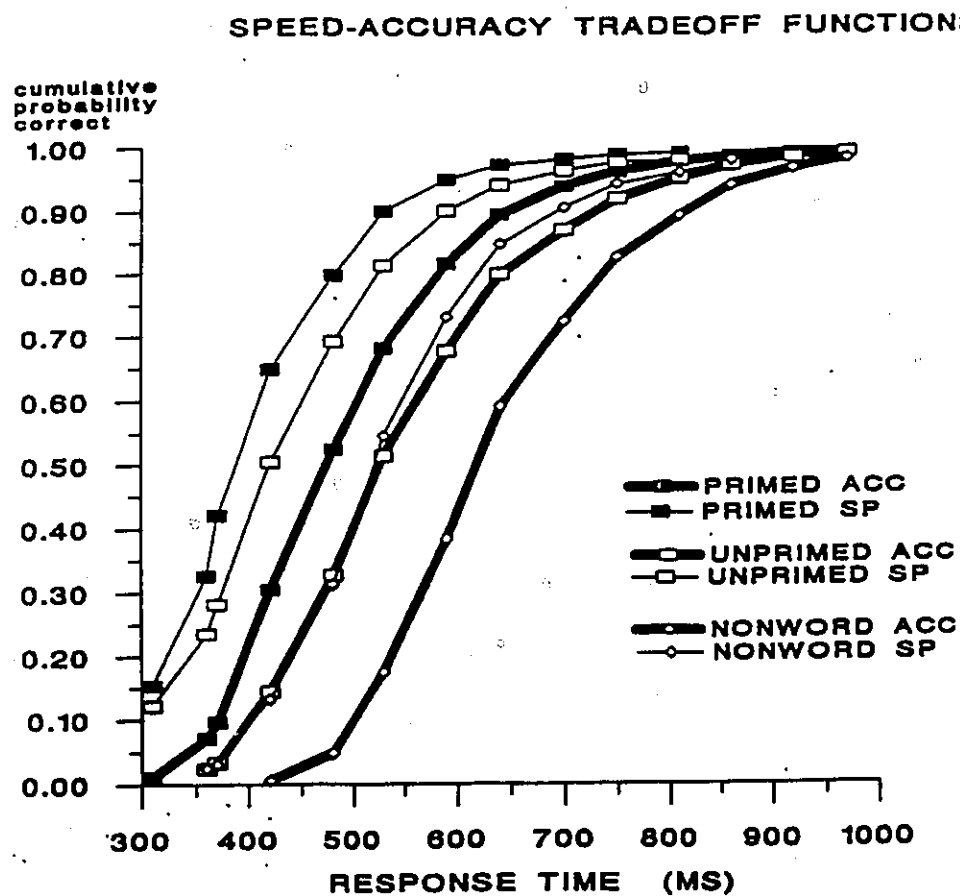


Figure 1. Speed-accuracy trade-off functions.

Table 1 also shows that positive responses were faster than negative responses.

When the target was a real word, correct (positive) responses were faster than incorrect responses ($p < .01$, Accuracy condition, unrelated targets; $p < .02$ Speed condition, primed targets; $p < .03$ Speed condition, unrelated targets). For nonwords, incorrect (positive) responses were faster than correct rejections ($p < .04$ Accuracy condition; $p < .001$, Speed condition).

Accuracy rates were higher in the Accuracy condition than the Speed condition ($F(1,9)=24.03$, $p < .004$). The type of target also had a significant main effect on response accuracy ($p < .01$, Huynh Feldt). Accuracy rates were higher for primed than unrelated words ($p < .02$, Accuracy; $p < .01$ Speed), and higher for unrelated words than nonwords ($p < .04$, Accuracy; $p < .01$, Speed). Condition and target type had a significant interactive effect on response accuracy ($p < .01$, Huynh Feldt). When the deadline changed from 700 msec to 450 msec, accuracy rates within subjects dropped by 3.5% for primed words ($p < .001$), by 5.0% for unrelated words ($p < .02$) and by 25.0% for nonwords ($p < .002$). The cost of making faster responses in the Speed condition was significantly reduced accuracy for nonwords compared to real words (Tukey's HSD, alpha .05).

The sensitivity index (d') fell from a mean of 3.5 in the Accuracy condition to 1.9 in the Speed condition ($t(9)=4.88$, $p < .001$). The response choice bias statistic ($\log B$) ranged across subjects from -3.01 to -1.72 in the Accuracy condition, and from -2.65 to -1.53 in the Speed condition. Negative $\log B$ statistics for all subjects in both RT conditions indicated a consistent bias toward the yes response classifying targets as real

words. The strength of this positive response choice bias did not differ significantly between conditions ($p > .22$). Although the Speed condition increased the likelihood of false alarms (incorrect positive responses to nonwords), it decreased the likelihood of hits (correct positive responses to real words).

Figure 2 compares the density of correct responses for each target type in relation to RT. The effect of the Speed condition was to shift these distributions to the left, toward fast RTs, and align the descending limbs of the three curves. The area between

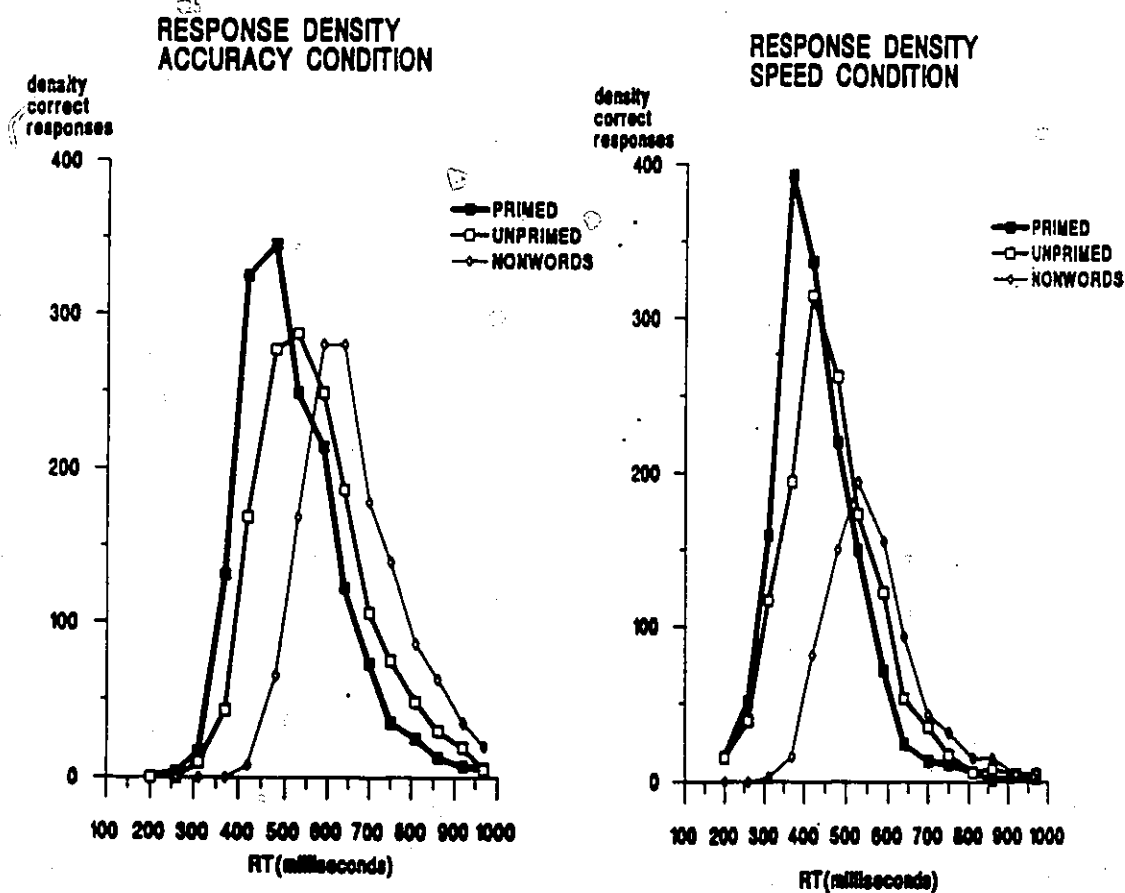


Figure 2. Density of correct responses as a function of RT.

the ascending limbs of the primed and unprimed distributions illustrates the faster RT and enhanced accuracy of decisions about a semantically primed word compared to decisions for words unrelated to the prime (i.e. the semantic priming effect). For nonwords, the smaller area under the Speed condition curve than under the Accuracy condition curve shows the marked reduction in the number of correct rejections when responses were fast.

In both RT conditions, the probability of nonword errors decreased as RT slowed, while real words errors were relatively few across RTs (Figure 3). Subjects began to

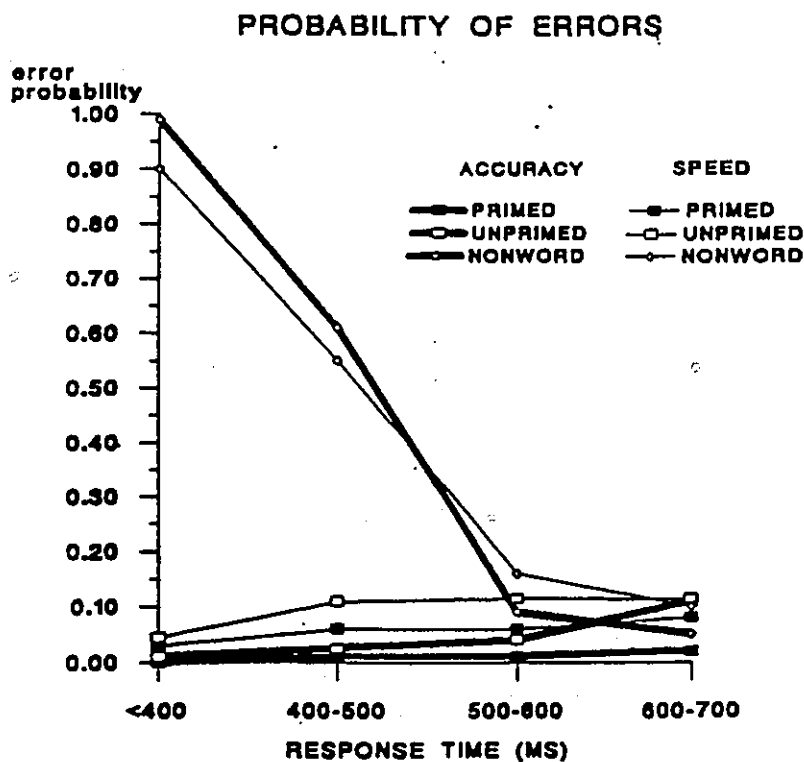


Figure 3. Probability of errors as a function of RT.

make more correct rejections than errors for nonwords at a mean RT of 508 msec (SD 48) in the Accuracy condition, and at a mean RT of 497 msec (SD 58) in the Speed condition ($t < 1$, NS). The probability of correctly rejecting a nonword approached zero when RT was less than 420 msec, then rose monotonically in all subjects. Between RT 420-580 msec, the mean probability of a correct rejection gradually rose from .15 to .91 in the Accuracy condition, and from .26 to .89 in the Speed condition.

Composite ERPs, Correct Trials. Grand averages for the two response conditions are compared in the upper portion of Figure 4. Target type and response condition did not have significant interactive effects on any ERP deflection. The latency of ERP peaks did not differ significantly between conditions. However, the amplitude of some deflections showed significant main effects of target type and/or response condition.

The vertex N130 and vertex N400 deflections elicited by the prime did not differ significantly between conditions. The amplitude of a widespread P235 deflection elicited by the prime was larger in the Speed condition ($F(1,9)=7.87$, $p < .03$). A slow increase in negativity (CNV) crossed the baseline 290 msec (SD 173) before target presentation in the Speed condition, and 260 msec (SD 161) before target presentation in the Accuracy condition ($p < .07$). CNV amplitude, largest at the vertex prior to target onset, did not vary significantly with target type ($F < 1$). Average CNV amplitude at the vertex was -4.0 uV (SD 2.2) in the Speed condition, compared to -2.9 uV (SD 1.9) in the Accuracy condition ($F(1,9)=12.56$, $p < .007$). Because pretarget amplitude differed significantly in

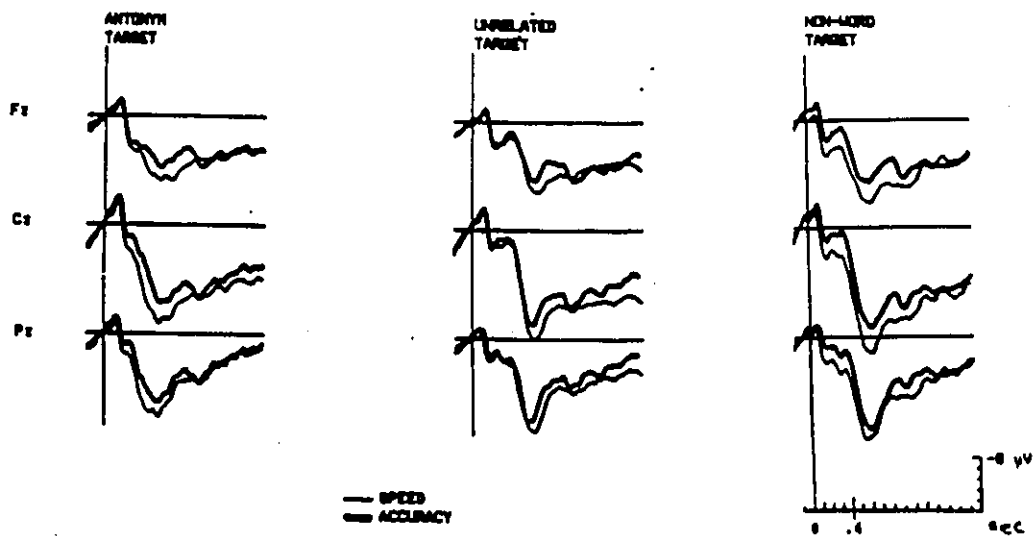
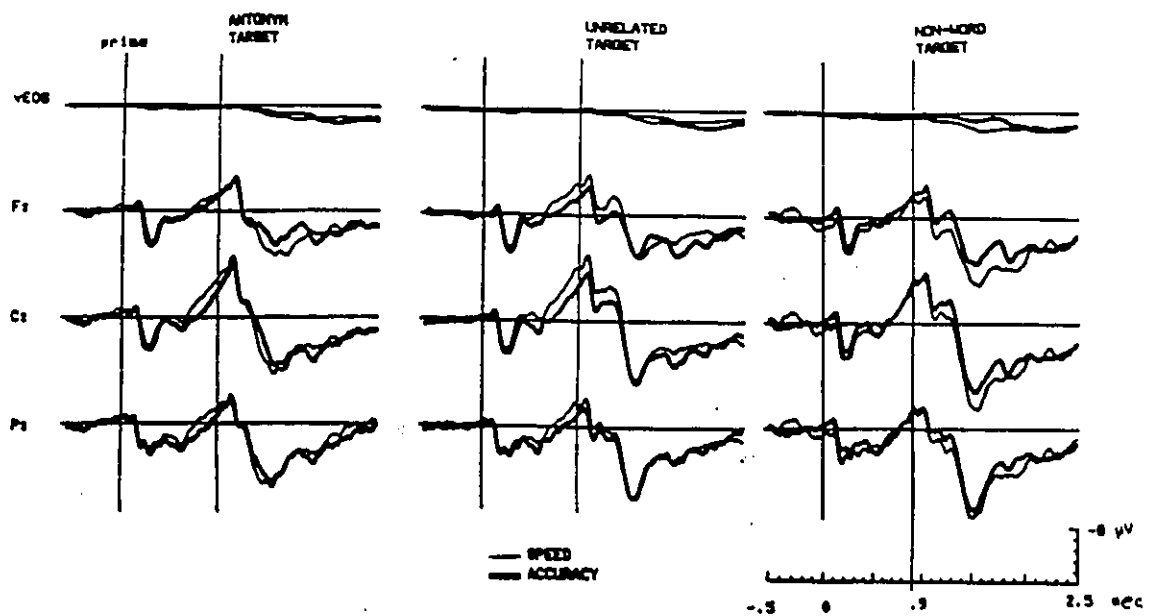


Figure 4. Grand averages Accuracy vs Speed condition.

the two RT conditions, the baseline for deflections following target presentation was computed as the average EEG in the 100 msec before target presentation.

As seen in the lower portion of Figure 4, posttarget N125 amplitude did not vary significantly with condition ($F < 1$) or target type ($p > .15$). Vertex N270 amplitude, however, was significantly larger in the Accuracy condition than the Speed condition ($F(1,9)=13.54$, $p < .01$), and varied with target type ($F(2,18)=12.23$, $p < .001$). N270 was smaller for semantically primed than unrelated words ($p < .006$, Accuracy; $p < .004$, Speed), but did not differ significantly between unrelated and nonword targets. When the target was unrelated to the prime or a nonword, vertex N270 was followed by negativity with a frontocentral distribution which peaked at 400 msec (SD 25). Note that N400 was not visible in the grand averages when the target was the prime's antonym. The amplitude of the N400 deflection elicited by unrelated and nonword targets was similar for these two target types ($F < 1$), although it was significantly larger in the Accuracy than the Speed condition ($F(1,9)=12.84$, $p < .007$).

The late positive complex (P600), largest at the vertex, was the only deflection to vary significantly in latency. P600 latency varied with target type ($F(2,18)=13.00$, $p = .001$) but not between RT conditions ($F < 1$). The mean latency of the late positive peak was 550 msec for primed words, 590 msec for unrelated words, and 650 msec for nonwords. While the difference between primed and unrelated words was not reliable because of large variability of P600 latency for primed targets, the P600 peak was significantly later for nonwords than for unrelated real words ($p < .02$, Accuracy; $p < .01$, Speed). P600 amplitude was significantly larger in the Speed condition than the Accuracy

condition ($F(1,9)=9.42$, $p < .02$). The effect of target type on P600 amplitude failed to reach statistical significance ($p < .07$).

Thus, in the grand averages, only ERP amplitude differed between RT conditions.

Individual Differences. Task performance indicated that further analysis was required to account for the large variance in response accuracy. With accuracy rates (%C) for the three target types as independent variables, multivariate analysis discriminated the same two groups of five subjects in both RT conditions (Hotelling's $T^2=21.27$, $F(3,6)=5.32$, $p < .04$, Accuracy condition; Hotelling's $T^2=129.53$, $F(3,6)=32.38$, $p < .001$, Speed condition). The same subjects clustered in the more accurate 'Group A' or less accurate 'Group B' regardless of the response deadline. Grouping was not related to age or gender. The equal number of subjects in each group was attributed to chance. Behavioural studies noting individual differences in a lexical decision task (Lewellen, Goldinger, Pisoni, & Greene, 1993), under speeded conditions (Luce, 1986), and in a speeded lexical decision task (Meyer et al, 1988) attribute variance in performance to individual differences in 'processing'. Unlike behavioural studies, however, this data set included ERP data which could illustrate individual differences in information processing. Moreover, a subjective factor was powerful enough to account for a significant proportion of the variance in response accuracy in both conditions when a multivariate test was applied. With some statistical and theoretical justification, despite a relatively small sample size, the RT distributions and ERPs for correct responses were partitioned according to accuracy grouping.

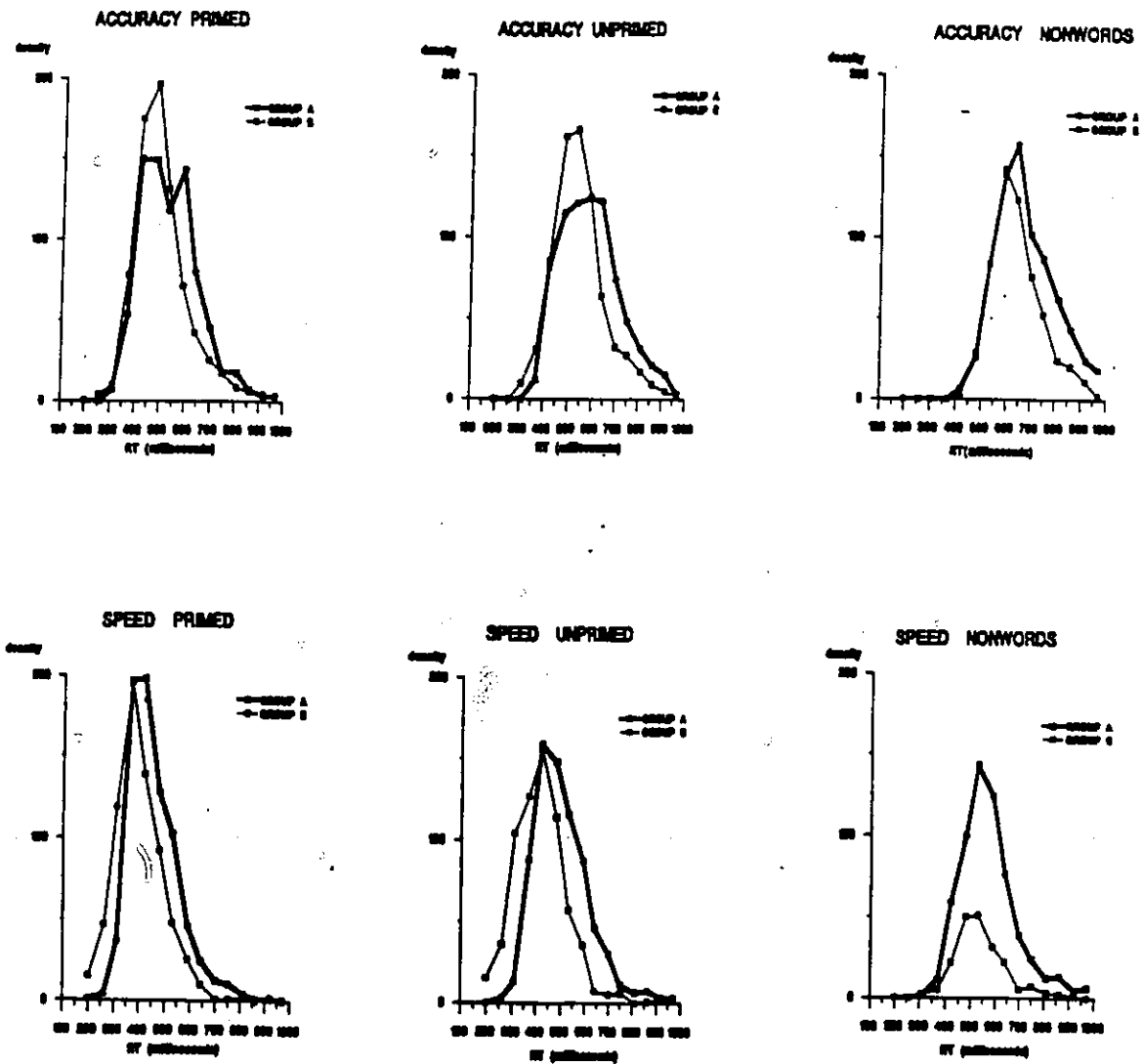


Figure 5: Density of correct responses in the more accurate

Group A (dark line) vs less accurate Group B (light line).

As seen in Figure 5, in both RT conditions, the more accurate subjects were somewhat but not significantly slower to execute correct responses (Hotelling's T^2 NS). Although the response choice bias statistic did not differ significantly between groups, the less accurate subjects' responses indicated a tendency to make fast positive guesses in the Speed condition. First, while the more accurate Group A's responses to real words in the Speed condition indicated 40 msec RT facilitation ($p < .05$) and enhanced accuracy ($p < .04$) for primed over unrelated targets, the semantic priming effect was not reliable in Group B in the Speed condition. Secondly, for unrelated targets in the Speed condition, although the groups were equally accurate, Group B was 75 msec faster than Group A (between groups $t(8)=2.60$, $p < .04$). Thirdly, while the more accurate group failed to meet the Speed condition deadline on more than half of the nonword presentations, Group B generally complied with the 450 msec deadline regardless of target type. Finally, Group B's low accuracy rate for nonwords in the Speed condition (33.4% C) equalled stimulus probability (1/3), significantly different from Group A's correct rejection rate of 81.0% C (between groups $t(8)=6.57$, $p < .001$). Nevertheless, for all subjects in both groups and in both RT conditions, the probability of correctly rejecting a nonword increased with RT, and became greater than the probability of misclassifying a nonword at approximately RT 500 msec.

ERPs for the groups differed significantly with respect to pretarget CNV, which began earlier in Group A (main effect of group $F(1,8)=6.11$, $p < .04$), and parietal P600 amplitude, which was enhanced in Group A (main effect of group $F(1,8)=11.59$, $p < .01$), notably when processing real words (group x target interaction, $F(2,16)=4.63$,

$p < .04$). On the other hand, the less accurate group's frontocentral N400 peak was prolonged (main effect of group $F(1,8)=7.20$, $p < .03$).

Figure 6 compares ERPs of the two groups in the Speed condition, in which Group B's overt responses suggested a tendency to make fast guesses. Significant group x condition interactions indicated that in the Speed condition the more accurate Group A processed the prime with larger N130 amplitude ($F(1,8)=14.45$, $p < .01$) and larger N400 amplitude ($F(1,8)=15.46$, $p < .01$) than did Group B. In the Speed condition, Group A's CNV began 200 msec earlier and was significantly larger than Group B's CNV ($F(1,8)=6.11$, $p < .04$). When processing targets (lower portion of Figure 6), N270 did not differ reliably between groups. For targets other than the prime's antonym, however, Group B's prominent and prolonged N400 was variable in amplitude, and its peak was significantly delayed for nonword targets in the Speed condition (group x condition x target interaction $F(1,8)=4.63$, $p < .03$). Group A's P600 amplitude increased significantly in the Speed condition (group x condition interaction $F(1,8)=6.68$, $p < .04$).

In summary, grouping subjects according to accuracy rates revealed significant differences in their ERPs. These individual differences, apparent in both conditions, were enhanced in the Speed condition. On the steep slope of a speed-accuracy trade-off function, where slightly faster RT results in a significant drop in accuracy, Group A subjects clustered above the cluster of slightly faster and significantly less accurate Group B subjects. Partitioning the variance showed some consistency *within* subjects when the response deadline changed, but significant differences in processing mode and output *between* subjects. ((

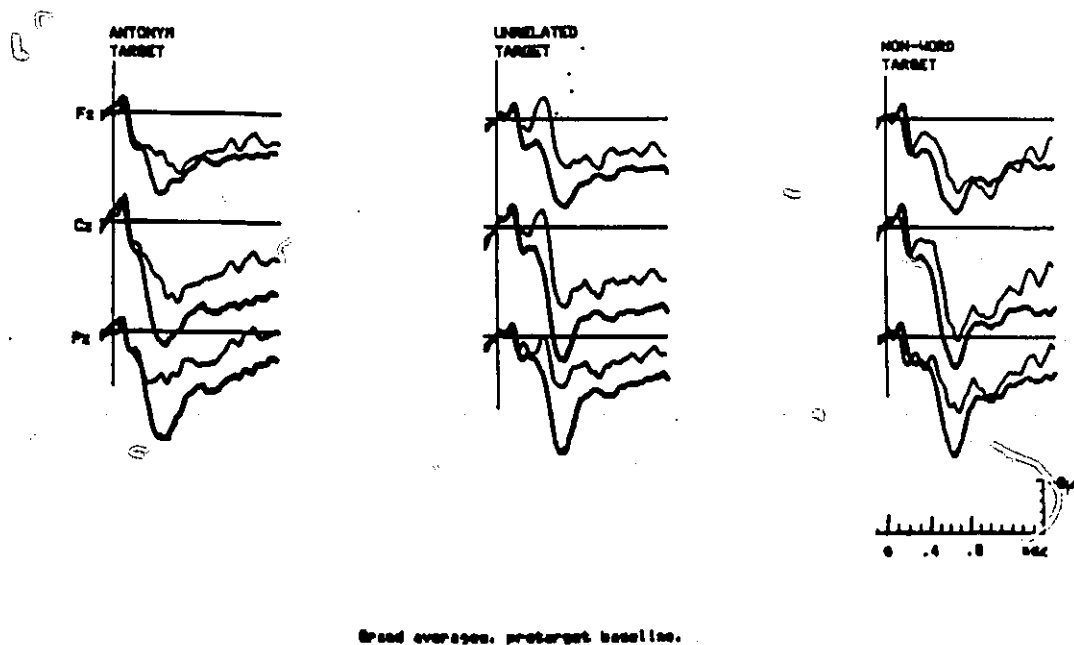
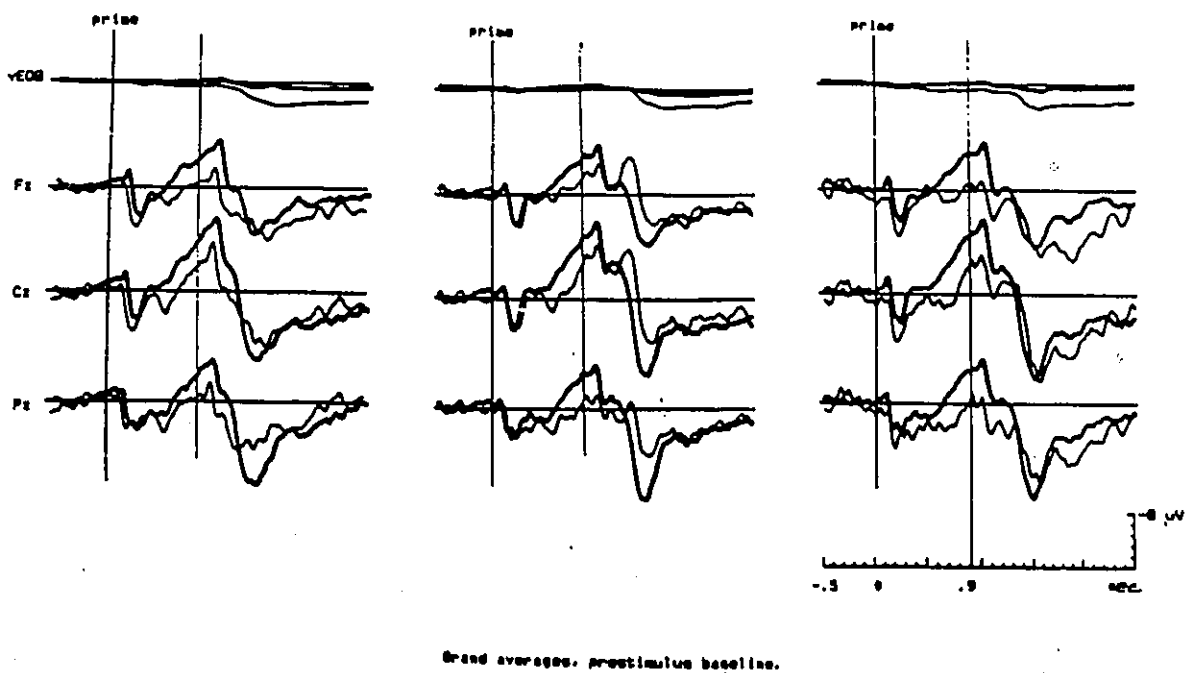


Figure 6. Grand averages in the Speed condition for the more accurate Group A (dark line) and less accurate Group B (light line).

RT Decomposition of ERPs. ERPs were also compared according to RT bins.

For this analysis, the average amplitude of a broad 'N350' deflection was computed as the average at Cz of all EEG samples 250-450 msec after target presentation. N350 included the epochs of the central N270 deflection and the frontocentral N400 deflection.

Figure 7 compares ERPs elicited during correct trials in the Speed condition. For semantically primed targets (left panel), as RT increased from less than 400 msec to RT 400-500 msec, N350 amplitude increased by 3.5 uV ($t(9)=2.61, p<.03$); when RT increased from RT 400-500 msec to RT 500-600 msec, N350 amplitude increased by 5.2 uV ($t(7)=5.79, p<.01$). For the other two target types, however, N350 amplitude did not vary significantly within subjects as RT changed.

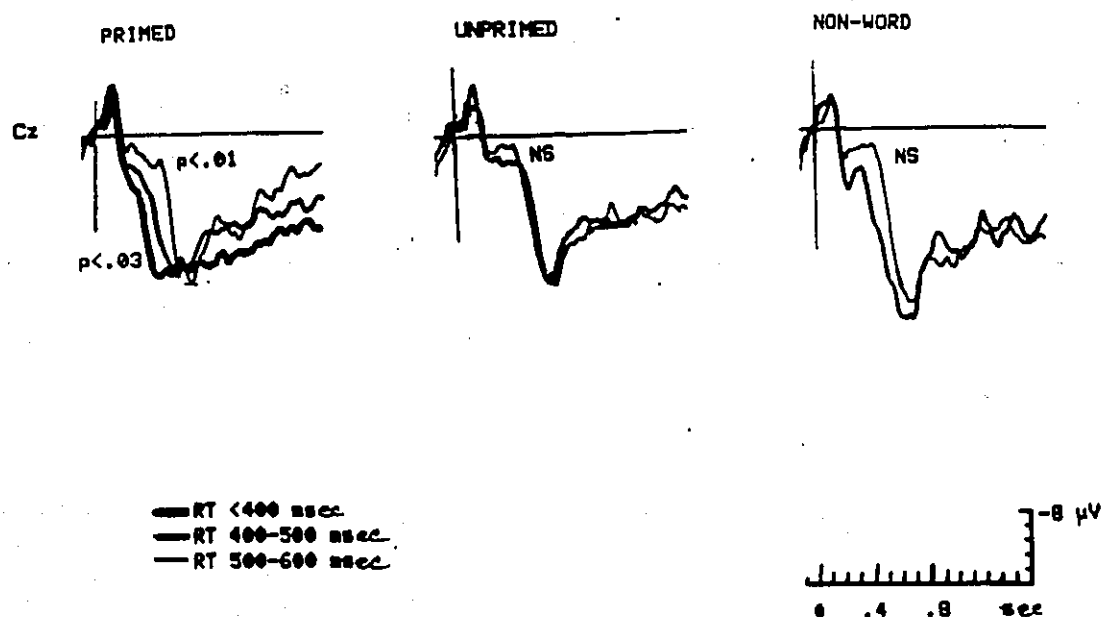


Figure 7. ERPs decomposed according to RT, Speed condition.

Figure 8 shows that at RT 400-500 msec (left panel), average N350 amplitude was 5.6 μV larger for unprimed than primed targets in the Accuracy condition ($t(9)=4.14$, $p<.01$), and 4 μV larger in the Speed condition ($t(8)=4.57$, $p<.01$). N350 amplitude was significantly smaller for primed than unprimed targets in both conditions on trials where RT was less than 500 msec, even though RT and response choice were the same for both target types. When RT was more than 500 msec (right panel), similar N350 amplitude for primed and unprimed targets implied that some 'primed' targets were not effectively primed.

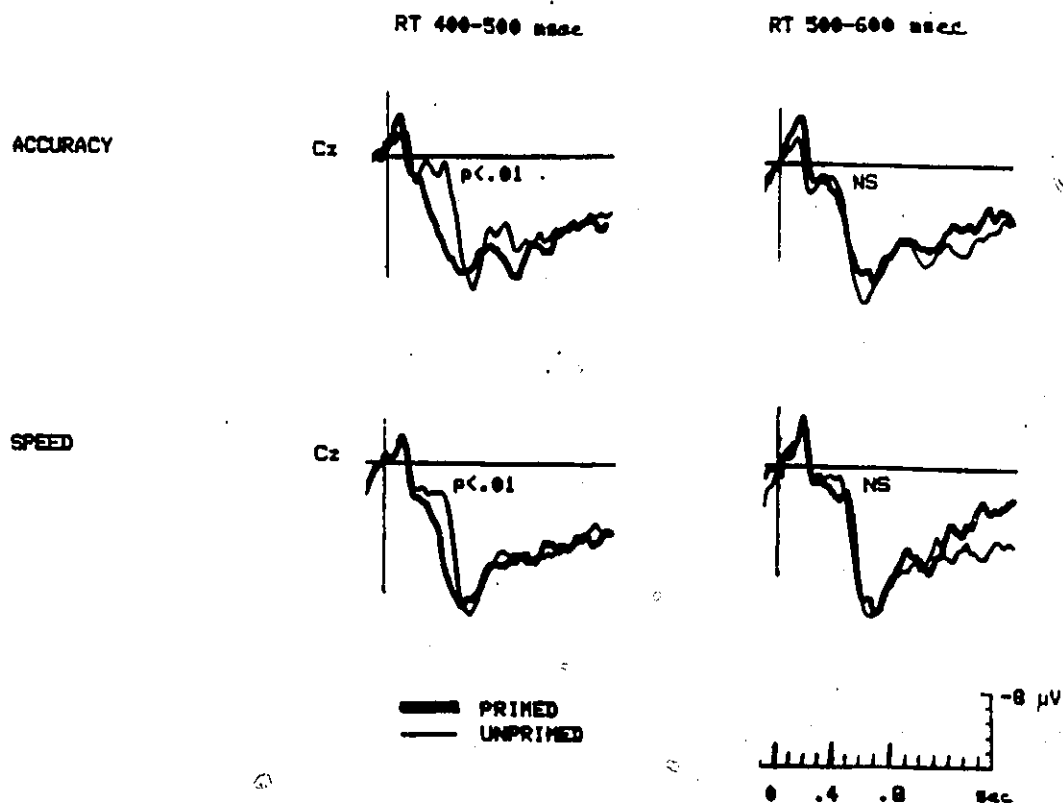


Figure 8. ERPs decomposed by RT, primed (dark line) vs unprimed (light line).

RT and the N400 portion of the broad N350 deflection were dissociated. At RT 400-500 msec, primed targets did not elicit N400, and unprimed targets did, even though RT was the same for both target types (Figure 8). The independence of response execution was also demonstrated in Figure 7, where the N350 amplitude elicited by unprimed and nonword targets did not change significantly within subjects, even as RT changed.

Correct responses to primed targets were executed in the Speed condition approximately 100 msec before the peak of the late positive complex. As the RT for primed targets increased from RT < 400 msec to RT 400-500 sec to RT 500-600 msec, the P600 peak shifted from 435 msec to 555 msec to 650 msec, respectively (Figure 7, left panel). The variability in P600 latency for primed targets, reported but unexplainable in the composite grand averages, depended on N350 variability. For unprimed targets, however, P600 latency was relatively stable at 590 msec, regardless of RT bin. For correct nonword trials, P600 latency was quite reliable at 650 msec; it was longer and variable only for the slowest trials (RT > 700 msec).

ERPs, Error Trials. Although errors occurred in all RT bins, 50.1% of the errors in the experiment were fast (RT < 500 msec) positive responses to nonwords in the Speed condition. Speed condition trials of nonwords provided enough correct and incorrect trials from enough subjects (n=7) to compare ERPs at RT 400-500 msec. Deflections were larger for error trials than correct rejections. However, amplitude variability among subjects was so great that neither the 3.0 uV difference in N350

between correct and incorrect trials ($p > .19$), nor the 3.3 μV difference in P600 ($p > .15$), was statistically significant. The late positive complex peaked at 650 msec for correct and incorrect nonword trials.

DISCUSSION

Lexical decisions were affected by the two independent variables, semantic context and response deadline, and by two subjective variables, response choice bias and individual differences in processing. The effects of the independent variables are discussed first.

Semantic priming effect. As expected, responses for semantically primed words were faster and more accurate than responses for words with no semantic relation to the prime. Correct RTs were about 200 msec faster in the Accuracy condition of this experiment than in an independent antonymic priming study in which subjects were asked to make lexical decisions as quickly as possible while maintaining accuracy (Campbell et al, 1990). Despite the 200 msec RT difference in the two studies, similar RT facilitation of 60-65 msec was observed for primed antonyms. This suggests that the semantic priming effect remains robust when responses are speeded. When subjects were required to make even faster responses in the Speed condition, the RT facilitation for semantically primed targets among the most accurate subjects was still significant, although it was reduced to 40 msec.

According to the composite grand averages, the N400 deflection associated with semantic processing was elicited by the prime, by targets unrelated to the prime, and by nonword targets (Figure 4). Small N270 and the absence of N400 in the composite grand averages of primed targets imply reduced attention to lexical-semantic information when

these words were processed. The facilitated processing of primed words appears to have been to a large extent automatic, given attenuated negativity for primed targets in all subjects in both RT conditions despite differences in response strategy. RT decomposition of ERPs revealed that the amplitude of a broad N350 deflection increased as the RT for primed targets slowed (left panel of Figure 7). Only the slowest trials of primed words elicited the frontocentral N400 portion (350-450 msec) of the broad N350 deflection. Since RT varied with N350 amplitude only for semantically primed words, an important factor in the RT facilitation for primed words is apparently facilitated semantic processing when the appropriate neural network has already been activated. The observed relation between brain and behavioural responses for semantically primed words is thus quite consistent with the automatic spreading activation theory (Meyer & Schavaneveldt, 1971; Meyer, Schavaneveldt & Ruddy, 1975).

Processes generating the N400 portion of the broad N350 deflection could be dissociated from RT, however. When the RT for real words was less than 500 msec, primed targets elicited little or no N400 while unrelated targets elicited a large N400 (Figure 8). Moreover, despite RT variation for unprimed and nonword targets, N400 was invariant within subjects (Figure 7). This dissociation implies that processes other than semantic processes contribute to RT variation. We shall examine N400 and response production more closely in a later section.

Fast correct responses for primed targets in the absence of N400 probably included fast positively biased guesses and responses based on partial information. On these trials, early operations common to all targets (N125, N270) may have provided

sufficient feature analysis and orthographic information, so that semantic analysis was unnecessary (cf. Seidenberg & McClelland, 1989). If subjects were predicting the target from the priming stimulus (cf. Becker, 1980; Neely, 1991; Neely et al, 1989), identification of one or more target letters may have provided a fast match with the prediction. Very fast responses compatible with the positive response bias also imply no competition between positive and negative response channels (Gratton et al, 1988).

Cases of ineffective semantic priming, identified by a RT later than 500 msec and negativity that included N400, occurred occasionally in all subjects. These cases were not related to target attributes of word length, word frequency, grammatical function, or grapheme to phoneme correspondence. Sporadic attentional lapses are an unlikely explanation of ineffective semantic priming, given the elicitation of N400 on these trials. One theory of semantic priming proposes that the prime and target form a compound cue for semantic memory retrieval (Ratcliff & McKoon, 1988). Since the strength of this compound cue depends on an individual's semantic history, a primed target which elicited N400 and a slow RT may have had a weak subjective association with prime. These trials occurred more often in the Accuracy condition, however, even though the same stimuli were presented in both conditions. It therefore seems likely that occasional semantic processing and slow response execution for primed targets depended on the subject's intention (Posner & Snyder, 1975). Deliberate attention to the meaning of a primed word in order to ensure an accurate response appears to be the best explanation for the occasional abolition of the semantic priming effect.

Variation in the negativity elicited by primed targets provides a parsimonious

explanation for the variable latency of P600 for primed targets. The attention paid to the features and meaning of a word evidently affects the completion time of stimulus evaluation processes. Since reliably correct responses for all target types, including nonwords, were executed in the Speed condition at least 100 msec before the late positive peak, the appropriate response was activated well before this deflection reached maximum amplitude. The peak of the late positive complex cannot therefore reflect the moment of response selection.

The lag between correct RT and the late positive ERP peak indicates that several processes after response execution, probably including somatic response feedback, contributed to the late positive complex. Since parietal P600 amplitude was significantly enhanced when the most accurate subjects processed primed and unprimed words (group x target interaction at Pz), memory updating processes may have contributed to the late positive complex, improving the accuracy of these subjects on subsequent trials of real words (Donchin, 1981; Donchin, Gratton, Dupree, & Coles, 1988). The amplitude of the late positive complex has also been positively correlated with decision confidence (Rohrbaugh, Chalupa & Lindsley, 1988), which may have been higher in the most accurate subjects.

Effects of the Response Deadline. Despite faster RTs in the Speed condition, ERP latencies were similar in the Accuracy and Speed conditions. The intention to respond faster in the Speed condition did not affect the latency of word recognition processes, probably because reading a single word is an overlearned skill involving

processes which begin and progress without intention. By contrast, the time at which a key press response is executed is largely under voluntary control. When ERPs were decomposed into RT bins, the latency of deflections for unprimed and nonword targets was quite stable within subjects as RT varied. Given the invariance of ERP latencies for targets other than semantically primed words, RT variability between and within conditions indicates that RT is affected by processes other than stimulus evaluation processes.

When the response deadline changed from 700 msec to 450 msec, small but significant accuracy reductions for primed and unrelated words were not attributable to response choice bias, since the bias favoured positive responses and real word errors were negative responses. The accuracy reduction was significantly larger for nonwords than real words because fast guesses were almost always positive, as expected when response priming biases subjects toward the positive response choice. More importantly, the monotonic increase in the likelihood of correctly rejecting a nonword as RT slowed ($p=0$ at RT < 420 msec; $p=.50$ at RT 500 msec; $p=.90$ at RT 580 msec), regardless of the RT condition, indicates that negative response choice information gradually began to flow to motor processes at the same time in both RT conditions. Selection of the negative *response* choice and successful transmissions of new negative *response* information -- *before* the peak of the late ERP deflection indexing completion of *stimulus* evaluation processes at about 650 msec -- signifies parallel distribution of stimulus evaluation and response production processes.

The amplitude difference in several ERP deflections between RT conditions supports the argument that subjects are likely to change their 'processing mode' to meet the demands of the response deadline (Luce, 1986). Significantly larger N270 and N400 deflections in the Accuracy condition suggest that subjects generally paid more attention to target features and meaning in the Accuracy condition than they did in the Speed condition (Figure 4). As discussed in the next section, however, the large variance in ERP amplitude and task performance is best understood by examining individual differences.

Individual Differences in Processing. Response accuracy and ERPs discriminated the same two groupings of subjects in both RT conditions. Interpretation of group differences will be limited to the Speed condition.

Among the most accurate subjects, ERP amplitude was significantly enhanced during processing of the priming stimulus (N130, N400), before target presentation (CNV), and during target evaluation (P600). Large pretarget negativities in the most accurate subjects could indicate a strategy of predicting the prime's antonym and rehearsing the expected target. If so, a target not matching the prediction (i.e. unrelated and nonwords) would be expected to activate semantic processes (N400). However, targets unrelated to the prime elicited early and small N400 in these subjects. An alternative hypothesis is that the more accurate group's large pretarget negativity reflects readiness to inhibit a rash response. Consistent with the motor inhibition hypothesis are this group's slightly slower correct responses for primed targets, their significantly slower

correct responses for unprimed words, and their non-compliance with the 450 msec deadline on more than half the presentations of nonwords. The centroparietal distribution of the late positive complex is also consistent with response inhibition (DeJong, Coles, Logan, & Gratton, 1990; Pfefferbaum, Ford, Weller, & Kopell, 1985). Large P600 amplitude in subjects with large pretarget negativity suggests that the amplitude of late positivity may partly reflect release from inhibition. Both overt and covert measures indicate that the strategy of the most accurate subjects was to inhibit response execution until target information was available.

Less accurate subjects generally complied with the 450 msec response deadline, at considerable cost to response accuracy for nonwords. Their overt responses indicated a tendency to execute fast positively biased guesses, since their responses for primed and unprimed words did not differ significantly, and their low accuracy rate for nonwords (33.4% C) was equal to stimulus probability. The ERPs of these subjects showed that the processing of unprimed and nonword targets elicited prominent and significantly prolonged N400. This frontocentral negativity contrasts with the large centroparietal positivity in more accurate subjects.

Anterior negativity has been associated with a resource-driven processing mode activated by difficult mental operations (memory search, visual search, mental rotation), and posterior positivity with a data-driven processing mode (Kok, 1990). Our results indicate that the amplitude of anterior negativity vs posterior positivity during a speeded lexical decision task is affected by the subject's strategy. It is possible that the semantic processes which generate N400 are related to speech production processes, while a

different brain organization subserves sense/nonsense judgments (Kutas & Hillyard, 1989). The prolonged frontocentral N400 in less accurate subjects, especially for nonwords, could indicate that they silently named unprimed and nonword targets to retrieve meaning. The RT compliance of these subjects suggests that devoting their attention to producing a response before target offset when attention resources were also required for semantic retrieval may have compromised semantic operations and therefore response accuracy. In contrast, subjects whose pretarget strategy was apparently to inhibit a response until target information became available made accurate judgments consistent with data-driven processing: parietal positivity was enhanced in these subjects.

Response Choice Bias. Response choice bias did not differ significantly between groups because in both conditions less accurate subjects, whose processing was resource-driven, made more nonword errors and more real word errors than did subjects whose responses were data-driven. In both groups in both conditions, near zero accuracy for nonwords at RTs less than 420 msec and an asymptote of near perfect accuracy for real words at fast RTs indicate that the positive bias probably provided the response choice on very fast trials. As RT approached 500 msec, the probability of correctly rejecting a nonword improved to .50, and reached .90 by RT 580 msec. The colinear increase in nonword accuracy functions implies that, regardless of the RT deadline or subjective strategy, nonword recognition processes gradually activated the negative response channel, outweighing the positive bias.

Studies which have measured peripheral EMG and the scalp-recorded lateralized readiness potential (LRP), but not response bias, indicate that a very fast peripheral EMG response is not related to stimulus content (Coles et al, 1985), but is driven by prestimulus response bias (Gratton et al, 1988). Our data, which measured response choice bias, but not motor potentials, indicate that in each subject the outcome of very fast trials was neither random nor close to stimulus probability (.33) or response probability (.50). A response choice bias apparently serves as the default choice for very fast responses. As target information becomes available, the biased choice is either compatible or incompatible with the response selected by central processes. When an incorrect peripheral choice is corrected by central processes before response execution, the late positive complex is delayed (Smid et al, 1990). The significantly longer latency of this complex for correct negative responses (650 msec) than for correct positive responses (590 msec) is consistent with correction of a bias favouring the yes response. Since the probability of correctly rejecting a nonword reached .90 at RT 580 msec, the bias was usually corrected well before the late positive deflection peaked at 650 msec.

The long latency of the late positive peak for nonwords appears to be due to response-related processes rather than prolonged evaluation of letter strings which do not exist in memory. Since nonwords were presented less frequently than real words, target type and probability were confounded in this experiment. When these factors are manipulated separately, and responses are not speeded, neither stimulus type (word vs. nonword), nor stimulus probability, nor the infrequent presentation of a nonword target significantly affects stimulus evaluation time; negative responses occur after the peak of

the late positive complex (Polich & Donchin, 1988). The latency of the late positive complex is not longer on catch trials of nonwords than on frequent trials of real words in an unspeded semantically primed task, although again nonwords are rejected after the late positive peak (Campbell et al, 1990). When responses are speeded, however, as they were here, the late positive complex is prolonged for nonwords. Selection of a negative response contrary to the response bias is apparently pushed back into the timeframe of the late positive complex, and the peak of this deflection is delayed. Cognitive processes related to a negative response, which occur after stimulus evaluation under unspeded conditions, must occur during the late positive complex under speeded conditions. Apparently in a lexical decision task, the latency of response selection processes, unlike the latency of stimulus-related processes, is consciously controlled.

Frontocentral N400 and Response Production. Negativity peaking at about 400 msec is elicited by lexical decisions and other tasks such as mental rotation (Stuss, Sarazin, Leech, & Picton, 1983; for a review see Kutas and van Petten, 1988). During semantic tasks specifically, PET studies indicate activation of left inferior prefrontal cortex and anterior cingulate gyrus (Peterson, Fox, Posner, Mintun & Raichle, 1988). The latter area, which is also activated during rapid uncued movement or imagined movement, has been suggested as a source of non-specific attention (Posner, Sandson, Dharwal, & Shulman, 1988). It is possible that frontocentral N400 during complex tasks reflects attention to one or more processes, rather than solely activation of a task specific

process, such as semantic retrieval. When attention is directed away from semantic processing and response execution is postponed, the scalp distribution of N400 attributed to incidental semantic processing is central-parietal (Kutas & Hillyard, 1989). N400 scalp distribution in an unspeeded semantic category task is posterolateral (Deacon, Breton, Ritter, & Vaughan, 1991). In the present experiment, the N400 elicited by the prime was centrally distributed, while the N400 elicited when a speeded response was produced was frontocentral and large only in some subjects.

When variance was partitioned, the ERPs of subjects who often executed fast guesses in the Speed condition showed a prolonged and prominent N400 for unprimed and nonword targets. Response facilitation for primed targets was reduced or abolished in these subjects. Response facilitation for primed targets was robust in subjects whose N400 was small for targets unrelated to the prime. It is unlikely that accurate subjects with a robust behavioural priming effect paid little attention to semantic information in unprimed targets, while subjects with an unreliable behavioural priming effect in the Speed condition carried out extensive semantic processing of unprimed targets. We therefore consider the possibility that a component of frontocentral N400 reflects the elicitation of non-specific attention resources when attention is simultaneously required for response production and semantic processes.

ERPs suggest that the most accurate subjects began to control response processes before target presentation, whereas less accurate subjects attended to response production after target presentation. The slow negative potential before target onset is associated with cognitive and motor processes (CNV), and with a readiness potential (RP) which

facilitates response execution (McCallum, 1988). As discussed previously, the early onset and large amplitude of this potential in the most accurate subjects suggested readiness to inhibit a rash response. Since response inhibition and response activation are probably independent processes (De Jong et al, 1990), the most accurate subjects appear to have divided response production processes efficiently, by inhibiting response processes before target onset and activating the appropriate response as target information became available. If motor processes were already inhibited because both fingers were prepared to respond, response execution contingent on target recognition or non-recognition required only activation of the appropriate finger. By reducing neural noise in motor processes through inhibition (RP), motor readiness may have facilitated execution of the correct response. The large amplitude of centroparietal positivity in these subjects would diminish ERP evidence of semantic processing, although overt responses indicate that it occurred. Among less accurate subjects, small pretarget negativity and large frontocentral N400 for unprimed and nonword targets suggest that the attentional demands, initiated after target presentation, of several response production processes (motor preparation, motor activation, fast response execution) competed for resources also required by semantic processes. The large and variable N400 on error trials may similarly reflect negativity related to the draw on attention resources, rather than negativity specific to semantic processing.

CONCLUSIONS

The small negativity usually elicited by semantically primed words suggests that the draw on attention resources required to decide the lexical status of a word is small when the appropriate neural network has already been activated. The amplitude of this negativity for primed targets probably reflects the attention paid to expected target features when RT is less than 500 msec, since little or no N400 on these trials implies little or no draw on attention resources to extract semantic information. Paying attention to the meaning of a primed word, however, elicits N400, prolongs evaluation time, and delays RT, thereby abolishing the facilitative effects of semantic priming.

When subjects are pressed to respond very quickly, attention to word features and meaning diminishes, although the time spent processing this information does not diminish. The intention to meet a short response deadline appears to shift attention away from stimulus-related processes to strategic processes involving readiness to respond, and to shorten the latency of response selection processes. This attention-based explanation of word recognition and response production processes stresses the subject's utilization of automatic and consciously controlled resources during a cognitive task. It differs from an arousal-based explanation of task performance which implicates the subject's emotional state. An attention-based explanation of word recognition and response processes is compatible with semantic priming theories of automatic spreading activation, expectancy and prediction strategies, or the compound cue theory of semantic retrieval. It is also

consistent with PET studies showing activation of anterior attentional and semantic areas during semantic tasks.

Processing a single word appears to involve for the most part overlearned and automatic processes which begin and progress without intention, whereas response production processes (motor readiness, response selection, response execution) can be controlled and adapted to task requirements. The parallel distribution of stimulus and response processes, and RT variability despite the relatively stable latency of ERP peaks, mean that the RT for a correct lexical decision is an unreliable estimator of the duration of stimulus evaluation processes. Furthermore, response choice may be accurate because of motor processes rather than word recognition and decision processes. Given a positive response choice bias and a short response deadline, fast accurate responses for semantically primed targets were executed about 100 msec before the completion of stimulus evaluation processes. For words unrelated to the prime, subjects who executed fast biased guesses achieved as many correct responses as subjects who executed significantly slower data-driven responses, despite similar evaluation time.

The frontocentral N400 elicited by targets unrelated to the primed semantic context is not a reliable index of semantic processes because it is confounded by negativity associated with attention to response production in subjects whose processing is resource-driven. In subjects whose processing is data-driven, N400 is contaminated by overlapping centroparietal positivity. The N400 of the composite grand averages resulted from averaging the ERPs of subjects whose processing modes differed. Since within subject averaging reduces EEG noise but not a constant source, and N400 was usually absent for

semantically primed targets, negativity peaking at about 400 msec can be associated with attention to semantic information. However RT does not index the duration of semantic processes because RT was dissociated from N400 amplitude and N400 latency. In fact, prolonged N400 in subjects with the fastest RTs suggests that fast guessing may focus attention on response production and delay attention to semantic information.

Information transmission from semantic to motor processes is probably not continuous (cf Miller, 1983; 1988; 1990; 1993). The dissociation of N400 and RT supports this conclusion. Although partial N400 output may have appeared to activate some correct responses for unprimed words, these fast positive responses can be attributed to positively primed guesses. The near zero probability of rejecting a nonword before RT 420 msec argues against any, let alone partial, transmission of negative information to motor processes before the N400 peak. Furthermore, a response selection process, occurring during the late positive complex under speeded conditions, appears to intervene between semantic operations and response execution. This process seems to occur if N400 output is incompatible with a positive response choice bias which functions as the default choice, or if N400 output is deliberately attended to ensure response accuracy. A response selection process comparing discrete semantic information and the default response choice would account for the same long 650 msec latency of the late positive peak for nonwords and ineffectively primed words. Without evidence of partial information transmission from N400 to motor processes, it seems reasonable to infer that semantic information extraction is a discrete processing stage completed before a response based on word recognition or non-recognition is executed.

The increasing probability of correctly rejecting a nonword after the N400 peak but before the late positive complex reached maximum amplitude could indicate continuous information transmission from a component source of the late positive deflection (the response selection process?) to motor processes. Response outcomes were quite consistent with a stochastic model which proposes partial information transmission and predicts the effect of a response choice bias (Ratcliff, 1988). Correct responses before the late positive peak are also consistent with stimulus evaluation and response preparation stages in parallel cascade (McClelland, 1979). Feedback processes consistent with a connectionist model (Seidenberg & McClelland, 1989) could account for the lag between RT and the late positive peak.

Response outcomes and ERP evidence of cognitive and motor processes before target presentation are *not* consistent with a model proposing that stimulus evaluation and response production are discrete processing stages (Sternberg, 1969). Serial processing stages would have yielded a sudden increase in correct rejections after the completion of stimulus evaluation processes, instead of the observed monotonic increase in nonword accuracy. Furthermore, the .50 probability of a correct rejection at RT 500 msec, rising to .90 probability of a correct rejection at RT 580 msec, well before the late positive ERP peak at 650 msec, indicates that partial information reached motor processes and outweighed the response choice bias before the completion of evaluation processes. A simple additive model is inappropriate to the lexical decision task because of the parallel distribution of word recognition processes and individually variable response production processes.

Transmission of partial information in other tasks has been inferred from movement-related potentials over prefrontal cortex (Osman, Bashore, Coles, Donchin, & Meyer, 1992; Smid et al, 1990). In future research, ERPs time-locked to response execution, rather than to stimulus presentation, should clarify the temporal programming of processes involved in conveying thought into action. The mechanisms underlying response choice bias are another subject for future research. This project suggests that a global bias is downloaded to provide a probabilistic default choice when stimulus evaluation processes have not had time to output local response choice information. Fast biased guesses would be consistent with activation of the extrapyramidal motor system.

Finally, ERPs illustrate individual differences in the covert processes underlying a tradeoff between speed and accuracy. A disposition toward a data-driven or a resource-driven processing mode may reflect a characteristic relation between thought and action that is exaggerated when subjects are required to speed response production. It is left to future research to explore ERP correlates of personality traits (eg compliance, compulsiveness, impulsivity) and other factors (eg verbal IQ, clinical syndromes) that may be tapped by speeding a cognitive task.

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