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HOW AUTOMATICALLY IS MEANING ACCESSED: A REVIEW OF THE EFFECTS OF ATTENTION ON SEMANTIC PROCESSING

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1. ABSTRACT

This chapter attempts to review electrophysiological data that stand at the intersection of two large domains of research: selective attention and semantic processing. Analogous behavioral studies will be discussed as a way of introducing the reader to some of the more complex paradigms, and providing convergent evidence. The focus of this review will be on data that add special insight into the issue of semantic processing in the absence of attention. However, paradigms which allow semantic activation in the absence of awareness will also be examined as these studies have also yielded data concerning automatic semantic processing. It is concluded that a great deal of semantic processing can occur in the absence of attention as well as in the absence of awareness.

2. INTRODUCTION

The extent to which word meanings are automatically processed continues to be of interest, as it impacts both the development of linguistic theories and explorations into the nature of communicative disorders. In retrospect, the debate regarding whether semantic stores could be activated in the absence of attention may have been spawned indirectly by the use of words as stimuli in studies which were really designed to test more general theories of selective attention. In particular, "late selection" theories of selective attention (1-3) owe their inception to the use of linguistic stimuli by these theorists. While previous studies using non-linguistic stimuli suggested that attention acted to exclude irrelevant stimuli at an early stage of processing, thus giving rise to "early selection" theories of selective attention (4-6), evidence from dichotic listening and related tasks suggested that even irrelevant words might be processed for their meaning (7-10). In particular, words which fit the context of the irrelevant message, or are highly salient to the subject (i.e. their name), are more often demonstrated to have been processed for meaning than others. The late selection view, which attempted to account for evidence of automatic semantic processing, purported that words are processed automatically (without attention or conscious mentation) up to, and including, the level of meaning. Selective attention, in this view, serves not to curtail processing of the irrelevant word but only to exclude it from consciousness. Critics of this literature have argued that the switching of attention could not be ruled out (11-12). More contemporary models such as those of Marcel (1983), which incorporate a system of weighted filters, have also been proposed in order to account for the interaction between attention and semantic content. Marcel based his model on data which demonstrated that an irrelevant word (a color name) which was masked to prevent its identification, could still facilitate the naming of a color patch. The irrelevant color name must have activated semantic stores even though it could not be identified. These data were less vulnerable to the criticism that subjects had switched their attention to the irrelevant channel. Stimuli which could not be consciously processed would be unlikely to initiate a switching of attention as might have been the case in the dichotic listening studies. On the other hand, the findings were considered controversial to the extent that the stimuli might have been more identifiable than was estimated. The majority of behavioral studies cannot easily refute the above criticisms because, by their very nature, behavioral measures usually only tap into the consciously controlled processing of information. Electrophysiological methods circumvent this difficulty to some degree, but as we will discuss, interpretation of electrophysiological data is highly dependent upon our knowledge of the functional significance of the components which serve as measures.

3. EVENT RELATED POTENTIALS RELEVANT TO THE MANIPULATION OF ATTENTION AND SEMANTIC PROCESSING

Within the context of examining the effects of attention on semantic processing, selective attention difference waves and the N400 most often serve as dependent measures. Difference waves, used to delineate selective attention effects (SAEs), are derived by subtracting the ERPs elicited by unattended stimuli from the ERPs elicited by attended stimuli. Early attentional effects such as these have been termed the negative difference wave by Hillyard (15-16), or alternately the processing negativity by Näätänan and colleagues (17). We have adopted the term SAE in order to avoid confusion, since the scalp topography, onset, and polarity of SAEs vary as a function of the physical properties of the stimulus cue which defines items as relevant. The difference waves which we will describe here are, in fact, positive difference waves.

The N400, a negative component with a peak latency usually in the range of 300 to 500 ms, commonly serves as a physiological index of semantic processing. The N400 is elicited by linguistic stimuli, including pseudo-words (18-19), provided that the subject attempts to process the stimuli for their meanings (20-22). When the task requires discrimination of words on a purely physical level (i.e. size of words) a negativity is elicited which is not modulated by semantic priming (20). The most straightforward interpretation of the N400, which we will advocate here, is that it reflects the processing required to activate the meaning which corresponds to the visual or auditory representation of the word or item. Others have argued, however, that the N400 reflects processing which occurs after the meaning of the word has already been accessed (i.e. a post-lexical interpretation).

The first studies to report the N400 manipulated its amplitude by varying the congruity or cloze probability of the terminal words of sentences (23-24). It was later concluded that the N400 reflected the process of integrating the terminal word into the context of the sentence. Since this time, the N400 has been examined using single word priming paradigms where the only context is the preceding word. Significant priming effects were found on the N400, in several of these studies, even though the SOA was too short to allow the operation of post-lexical processes (25-27). Regardless, the view that N400 primarily reflects post-lexical integration has been retained by many investigators (29-32).

There are two main bodies of evidence which have been used to perpetuate this notion. In one study, Holcomb (31) found that degraded stimuli elicited N400s which peaked later than for undegraded stimuli but the latency difference was constant, regardless of whether the words were primed or unprimed. Holcomb maintained, appropriately, that priming should have interacted with degradation if the N400 reflected an aspect of lexical/semantic processing, such as the analysis of word form or meaning. The fact that these variables did not interact, he suggested, was evidence that N400 reflects a post-lexical process (i.e. one occurring after the meaning of the word was accessed). A concern regarding this study, however, is that a large late positivity, the P300, which overlapped the N400, was earlier for primed than for unprimed words and was larger and earlier for nondegraded than degraded stimuli. The P300 is known to be post-lexical in that it reflects stimulus classification processes for both linguistic and nonlinguistic stimuli (33-35, 24). Since variability in the P300 would have contributed to the difference waves, upon which the analyses were based, its presence is a possible confound as regards interpretation of the data. In contrast to Holcomb, we have found a significant interaction between degradation and priming on the onset of N400 in an experiment which was designed so as to minimize the contribution of P300 (36).

The data of Brown and Hagoort (30) constitute a second body of evidence which has been argued to support a post-lexical role for N400. In several experiments, a pattern mask was presented before and after the primes, rendering them unidentifiable. The rationale behind this manipulation was that if the N400 reflects automatic semantic processing, it would be modulated by priming, even when the primes could not be consciously recognized. An N400 was obtained under both masked and unmasked conditions, but its amplitude was modulated by the relatedness of the preceding prime only when the prime was not masked and could be identified. Two more recent studies, however, have demonstrated that the N400 could be modulated as a function of repetition (37) and semantic priming (38), even when the stimuli were masked. The latter two studies suggest that the absence of priming in Brown and Hagoort (30) is not so much a reflection of the processing nature of the N400 as differences in their methods and individual differences among their subjects. In our study (38) several subjects were excluded because they did not get priming in the unmasked, control condition. Since Brown and Hagoort used a four group design, where none of the subjects in the masked ERP condition ran in the unmasked ERP condition, they could not have known whether some of the subjects in the masked condition would not have shown priming even without masking. In line with this, priming effects on reaction time (RT) were also much smaller in the Brown and Hagoort experiment using masked primes, suggesting that at least some of their subjects may not have demonstrated priming whether or not the primes were masked. In other words, because a between-group design was used, it could not be determined whether the same subjects who were run in the masked priming condition would have demonstrated normal N400 priming effects to unmasked stimuli.

The post-lexical process which Brown and Hagoort discuss was initially proposed as a mechanism which might account for extraneous variability in RT during lexical decision tasks (39). Subjects performing lexical decision are thought to adopt a strategy by which they use the "context" provided by the prime to facilitate their response. In essence, the subject checks back to the preceding word. If the current word is related to the prime then it is easier to tell if it is a real word. To clarify, it is response choice that is proposed to be facilitated by this hypothetical mechanism. Further evidence then, against this type of post-lexical mechanism having influence on the N400, is that speed-accuracy tradeoff manipulations, which are known to affect response choice time, do not affect the latency of N400. Condor and Campbell (1991) (40) obtained the usual effect of RT being shorter when subjects were told to stress speed than when they were encouraged to stress accuracy, whereas the latency of N400 remained constant under these same manipulations. If the N400 were engendered by a post-lexical process, particularly of the kind discussed by Brown and Hagoort, then it should be sensitive to manipulation of the subject's level of certainty, such as occurs in speed-accuracy paradigms.

In summary, the extant literature suggesting a post-lexical locus of N400 can be refuted, and the remaining literature on this topic is consistent with the N400 reflecting an aspect or aspects of lexical/semantic processing. The importance of this circumstance, in the context of the present review, is that the presence of priming effects on N400 can be interpreted as evidence that lexical/semantic processing has been modulated. On the other hand, as will be discussed later in this chapter, the absence of N400 priming effects cannot rule out the activation of semantic stores.

4. SELECTIVE ATTENTION

McCarthy and Nobre (1993) (41) combined semantic and repetition priming in an investigation of the effects of spatial selective attention on semantic processing. This study was designed to pit classic early versus late selection theories against each other by instructing subjects to attend to either the left or right visual hemifield while maintaining central fixation. In this way, all the stimuli on a given trial were visible in parafoveal vision, but those on the left or the right were alternately designated attended and unattended. The concept of early selection predicts that the unattended stimuli would be filtered out early on the basis of spatial location, and would therefore exert no (42), or little (43, 5) influence on the processing of subsequent words . In the ERP measure, this would appear as identical waves for primed and unprimed words in the unattended condition, and facilitation for primed waves in the attended condition. In contrast, the late selection theory predicts that even unattended stimuli are processed by classification systems, or logogens, up to a semantic level (44-45). Only at this point are the stimuli selected for conscious inspection or disregarded. McCarthy and Nobre (41) reasoned that, if this theory were correct, semantic priming effects should be seen on the N400, regardless of the attentional status of the eliciting words. These authors, however, found no evidence for late selection theories in that semantic and repetition priming effects on the N400 occurred only for the attended words.

The extent to which unattended stimuli are processed was investigated by Kellenbach and Michie (1996) (46), using color to designate the attended and unattended stimuli. In general, color is a highly effective cue for directing attention to the to-be-attended stimulus, as indexed by the early latency SAEs produced in a wide range of visual paradigms (47-49). By factorially combining semantic priming (prime/target presentation) with attentional status (attended/unattended) four conditions were created that allowed a direct test of semantic priming as a function of whether or not the prime preceding the target was attended. The four conditions were: attended prime followed by attended target (A/A), unattended prime followed by unattended target (U/U), attended prime followed by unattended target (A/U) and unattended prime followed by attended target (U/A). Attended and unattended were defined by their color. Their first experiment required a binary lexical decision response to all targets. The stimuli consisted of 160 semantically related pairs and an equal number of unrelated pairs matched for word length and frequency. To these words were added 720 orthographically legal and pronounceable non-words. In the first experiment, subjects indicated whether the attended stimulus was a legal word by pressing one of two buttons on each trial. In the second experiment, subjects were required to make a button press only if they saw an attended non-word. Significant priming effects were obtained on the N400, as evidenced by the prime ERP being more negative than both the target ERP, and a control ERP elicited by orthographically legal non-words, in the 350-600 ms window. These effects occurred in the A/A and A/U conditions of both experiments. The authors concluded that the determining factor in activating semantic priming is attentional processing of the prime. Behavioral evidence of negative priming was obtained for the U/A condition of experiment 1 but was not replicated in experiment 2.

Otten, Rugg, and Doyle (50) also investigated the extent to which unattended words are processed by using color to designate the attended and unattended stimuli in a lexical decision task. In Otten, Rugg, and Doyle, relevant and irrelevant stimuli were simultaneously presented in pairs slightly above and below fixation. The factors of word repetition (first presentation/second presentation) and attentional status (attended/unattended) were manipulated to produce the same four combinations as in Kellenbach and Michie (46). In addition to these conditions using words, a parallel condition was constructed employing non-words. The interval between stimulus pairs was relatively long, at 2.58 seconds, with each pair appearing for 80 ms. Under these conditions a large repetition effect was observed for the A/A condition. This effect appeared as a sustained positivity with a Cz maximum, relative to average waves obtained from first words, emerging at 400 ms and lasting until around 800 ms post-stimulus. The onset of this positivity was 150-200 ms later than in previous studies employing color as the attentional cue. This delay was thought to be due to the high "filtering cost" of selecting relevant information that was presented in close spatial proximity to irrelevant information.

A smaller, but significant repetition effect emerged for the A/U condition. This effect may have been due to unconscious lexical or semantic activation, or, as suggested by Otten and colleagues, may have reflected heightened activation of the orthographic features of the attended word, such that the detection of even a few of these features during the presentation of the unattended target was sufficient to initiate further processing. No effect of repetition was found for the U/A or U/U conditions. In isolation, these findings might cast doubt on the notion that unattended primes are processed post-perceptually, thus supporting an early selection model of attention (4). A second experiment performed by these authors, however, would argue against this interpretation.

The second experiment conducted by Otten, Rugg, and Doyle was identical to the first, except for the addition of a spatial cue in the form of an arrow at fixation, which indicated the position of the to-be-attended word. Cuing occurred for 1586 ms, with an offset 150 ms before the to-be-processed trial. The effect of this cue was dramatic. As in the first experiment, repeated words in the A/A condition produced a large, Cz maximum positive shift in the region of the N400, which in this case, onset at 300 ms. However, both the U/A and A/U conditions also produced small, but significant repetition effects at the lateral electrodes. Most surprisingly, the usual repetition positivity was significantly reversed in the U/U condition, such that 2nd presentations produced a sustained negativity across the scalp. This occurrence of apparent inhibition was termed by Otten *et al*. the negative repetition effect.

Attention is often thought to exert it's influence by selectively activating information processing pathways, but a flip side exists as well. Tipper and Driver have been instrumental in describing the role of inhibition in information processing (see 51). While inhibition may be equally as important as facilitation for normal cognition, a majority of theorizing involving semantics has focused on facilitation (see 52). In fact, most theories posit effects of selection for attended stimuli only (53-54).

Otten, Rugg, and Doyle liken their inhibition effect to the negative priming observed in selective attention tasks using pictorial stimuli (55-56). In these studies, line drawings of novel shapes were presented overlapping each other, in one of two colors. The unattended shapes, when later attended, were responded to more slowly than the attended shapes, and more slowly than a neutral condition composed of shapes that had been neither ignored nor attended previously. A similar phenomenon, the distractor suppression effect, was reported by Neill and Westberry (57) who used the irrelevant information from the preceding trial in a Stroop task to serve as the relevant target information on the following trial.

It has been proposed that the representation of the ignored image is stored in memory with information to inhibit its processing if encountered again. This information has been termed an "ignore tag" (56). It is, at first glance, unparsimonious to posit the addition of information to irrelevant information in the form of an "ignore" signal. One may ask why the semantic system would bother to mark information as irrelevant instead of simply filtering it out. This question bears directly on the early versus late selection debate. If filtering occurs early, and in a fairly thorough manner, then it would be nonsensical to propose that ignored information gets "tagged" in any way in memory. The system would be storing information that it had already filtered out, and thus any resource savings accomplished by early selection would be diminished. If an ignore tag were to be appended to each irrelevant bit of information encountered by the system, for the purpose of preventing it from being processed needlessly in the future, then this would still require the processing of that item's lexical entry for the purpose of adding the "ignore" information.

For these reasons alone, it would seem more parsimonious to interpret the phenomenon of negative priming as suggesting that unattended information is processed extensively by the perceptual and memory systems. In support of late selection, data have been reported which would suggest that the inhibition occurs at the level of the semantic representation, since items that are semantically related to the ignored word are also inhibited (58). This phenomenon has been termed "automatic spreading inhibition." Consistent with this terminology, Neill and Westberry (57) demonstrated that negative priming can occur at intervals as short as 20 ms between the previously ignored stimulus and the new, to-be-attended presentation of that stimulus, which within the framework of Neely's model, could only be attributable to an automatic process (52). However, negative priming can persist up to 4 seconds (59). Using a paradigm similar to Neely (52) we obtained automatic priming effects on the N400 which endured for at least 2 seconds (28). Thus it is possible that once initiated, inhibition is maintained automatically.

A similar explanation for negative priming can be found in the instance theory of automaticity (60). Logan proposes that the appearance of a stimulus causes the retrieval of any past processing instances of that stimulus, including any previous responses made to it. If a match occurs between previous response information and current task requirements, then processing can proceed automatically. If a mismatch occurs, then attention demanding control processes operate to resolve an appropriate new response. While this theory may account for negative priming due to repetition of stimuli, the automatic spreading inhibition phenomenon which we have discussed, and cross modal priming studies (61-62) have shown that negative priming can occur at the level of semantic representation. The negative priming effects on N400, reported by Otten *et al*., are consistent with a semantic locus for negative priming effects in that, as we have argued, the N400 reflects lexical/semantic processing. Converging behavioral evidence that the locus of the effect is not related to response execution time has been reported by Tipper, MacQueen, and Brehaut (63) who employed a paradigm which was designed to dissociate motor response effects from more "central," cognitive effects. In view of the fact that Otten, Rugg, and Doyle obtained ERP evidence of negative priming on trials where no response was required, negative priming cannot be exclusively due to response-related processing, although these might contribute somewhat to behavioral (RT) effects.

Most recently, Okita and Jibu (64) have extended the work of Otten, Rugg, and Doyle (50) and similar studies by investigating selective attention effects and repetition priming in the auditory modality. Subjects were presented with word pairs simultaneously in both ears and instructed to attend to the information from one ear at a time, thereby creating four conditions similar to those in Otten, Rugg, and Doyle. Subjects attended to only one ear at a time on each block of trials, with half of the subjects listening in the order LRRL (L=left, R=right), and the others receiving RLLR. Okita and Jibu found a strong attenuation of the N400 in the A/A condition, but no significant differences between 1st and 2nd presentations in the U/A or U/U conditions. The N400 component produced by second presentations of words in A/U trials, however, was attenuated compared to first presentation of U/A trials. This effect just missed significance ($F(1,13)=4.49$, $p < .06$). In spite of this near significant effect, these authors viewed their results as providing strong support for early selection theories, but acknowledged that early selection filters may act to attenuate, not prevent further processing of unattended stimuli (as per 64). Okita and Jibu state that because this experiment was auditory in nature, it is possible that the effect seen on A/U trials represents rapid switching of attention to the unattended channel. This argument is reminiscent of the unresolved debate begun when close shadowing of messages in dichotic listening tasks produced involuntary switching to the attended ear in order to follow the semantic content of messages (65, 5).

Until this point we have limited our discussion of ERP studies to the effects of priming on the N400s elicited by irrelevant words. In a number of studies, evidence of the semantic processing of irrelevant words was reported in the absence of any priming effect on N400. In an auditory paradigm, where stimuli were presented dichotically and stimuli in one ear were designated relevant, Bentin, Kutas, and Hillyard (66) found that the N400 was sensitive to semantic priming effects only in the attended ear. In a subsequent behavioral lexical decision task, however, responses were faster for stimuli that had been previously seen, regardless of whether they had been ignored or attended. The results of the lexical decision task are not what would be expected if unattended stimuli had been screened from further processing before semantic analysis. Bentin *et al*. concluded that while both attended and unattended stimuli are extensively processed, attended stimuli are more available for conscious recollection.

Similar findings were reported by Czigler and Géczy (67), who used a comparable selective attention paradigm. Their subjects performed a lexical decision task in which relevant and irrelevant stimuli were designated by color, and semantic priming was manipulated. Words and non-words that were presented in the irrelevant color produced N2 and N2b, without any N400 priming effect. A later recognition task indicated that emotionally salient words were remembered better than emotionally neutral words, indicating that at least some semantic processing occurred in the absence of an N400 priming effect.

Further data supporting late selection was obtained in our own selective attention study (36). As in Czigler and Géczy, color served as the selection cue, and semantic relatedness of the words was manipulated. In our experiment, however, a neutral condition was included in order to allow attentional effects to be divided into facillitory and inhibitory components. In this condition the subject's task was to indicate whether the words were presented in red or blue letters.

A comparison of the ERPs elicited by primed words with those elicited by unprimed words revealed significant priming effects on the N400 only in the attended conditions. While this provided no direct evidence for semantic processing in the absence of attention, some semantic processing may have occurred, as indexed by the onsets of the SAEs. The SAEs derived from the subtraction of irrelevant from relevant condition waveforms showed a characteristic frontal positivity and posterior negativity, as reported in other studies that used color as a channel defining cue (68-69). The SAEs associated with primed words onset significantly earlier than for unprimed words. This onset difference was not consonant with accepted explanations of selective attention effects. Traditionally, SAEs have been thought to reflect the assignment of more controlled resources to the processing of relevant stimuli than to irrelevant stimuli (70). In our study, however, the subjects selected on the basis of a non-semantic feature, color. Thus, the determination of the relevance or irrelevance of each stimulus should have taken approximately the same amount of time whether or not the words were semantically primed. Since this was not the case, an alternative explanation was required.

The SAEs for primed and unprimed words were elicited by words which were equivalent in every respect except for degree of semantic relatedness. Thus, the changes in the latency of these components must reflect differences in semantic processing. We proposed the involvement of an inhibitory mechanism that acts to suppress information from unattended stimuli, such as the negative priming mechanism discussed above. The presence of inhibition was supported by the finding that ERPs elicited by unattended words were more positive compared to the neutral condition, whereas the ERPs elicited by attended words were more negative than those obtained in the neutral condition. In order to explain the latency differences in the SAEs as a function of priming, we suggested that inhibition may be invoked in this paradigm in order to facilitate performance by preventing ignored words from impinging upon consciousness.

The absence of what has been termed the "intervening item effect", or "interposition effect" (see 27) further supports the view that the irrelevant words were inhibited. Interposing an unrelated word between two related ones, as in the sequence CAT-TRUCK-DOG, usually prevents priming from occurring. The circumstance that priming effects were obtained in our task, where irrelevant unrelated words were interspersed amongst attended, related words, means that activation of the semantic representations of their relevant words must have been inhibited, otherwise no priming would have occurred for attended words (priming would otherwise have been disrupted by the unattended words that intervened between the attended words).

The disruption of priming by an intervening item has also been demonstrated in two studies using ERPs (27, 38). In both cases, the usual N400 priming effects were observed when the related words were presented such that they were sequentially adjacent to each other. No significant priming was associated with trials where related items were sequentially separated by an unrelated word. These results were obtained even when the intervening words were masked to prevent subjects from recognizing them (38). This suggests that it is the mere activation of semantic stores which gives rise to the intervening item effect. As we have stated, however, the intervening item effect was absent in our selective attention task. The circumstance that priming effects were obtained in our selective attention task, where irrelevant unrelated words were interspersed amongst attended, related words, means that activation of the semantic representations of the irrelevant words must have been inhibited otherwise no priming would have occurred on attended words (it would have been disrupted by the irrelevant unrelated words). The SAE onset effects were replicated in a second experiment.

In the second experiment some of the stimuli were degraded, thereby increasing the difficulty of the processing task. Degradation caused a significant delay in N400 onset on both attended and unattended trials. The effect of degradation on the onset of N400 underscores our contention that irrelevant words are indeed automatically processed. If they were not, degradation should have had no effect on the N400 elicited by irrelevant words. Moreover, degradation interacted with priming in both the attended and irrelevant conditions, indicating that the automatic processing had progressed to the level of meaning. The replication of the SAE onset differences in this experiment and the effects of stimulus degradation are in keeping with late selection theories.

5. THE ATTENTIONAL BLINK

The attentional blink (AB) refers to a brief period of perceptual suppression that occurs after the presentation of a task-relevant stimulus (target) during a rapid serial visual processing task (RSVP) (71). In an RSVP task, stimuli are presented one after another in sequence at a rate of between six and 20 items per second, usually in the same spatial location. The "blink" occurs within a window extending approximately 180-500 ms, after the first target. The effect of the blink effect is to lower detection rates and impair identification for stimuli that occur within this time window (72). Shapiro (71) reviews evidence that this phenomenon is not due to low level visual processes such as pattern masking, and in fact, represents attentional suppression of stimuli during the blink. Raymond, Shapiro, and Arnell (72) note that the time window within which the attentional blink to the probe occurs (in their experiment 180-450 ms), is not known to produce effective pattern masking under most conditions (73). Furthermore, the reduction in probe detection was not found in conditions in which subjects were not required to identify the target. As low level masking occurs in both detection and identification paradigms, these data also suggest that the AB is an attentional phenomenon.

Other behavioral data from the AB paradigm also point to the idea that semantic processing can occur in low attention conditions. Shapiro, Caldwell, and Sorenson (74) used a subject's own name as a stimulus, and found that it resisted the AB significantly compared to common English nouns, and even other names. While this effect was robust, it leaves open the question as to what about the subject's name was responsible for the lack of AB when it served as a probe. Moray (7) was the first to discover that presenting the subject's name among unattended stimuli during a selective attention task could capture attention, but it has never been fully explained how the name acts to capture attention. If meaning is the key factor inducing attentional capture, then a direct test could be performed by using strongly associated words as the target and probe, and looking for modulation of the AB as compared to weakly, or unrelated pairs.

Shapiro, Driver, Ward, and Sorenson (75) reported that words that occurred during the attentional blink served as effective primes, mirroring numerous masked priming studies (see 11, for a review), but they did not examine whether words that are congruent with a specific semantic context would be more resistant to the blink.

While identification is impaired by the AB, some semantic processing still occurs in the absence of awareness. In a variation of the AB paradigm (76) the semantic relatedness of the probe (T2) was varied in relationship to the first target (T1). Strongly related probes were recalled significantly more than unrelated probes. The identification of T1 caused a subsequent decrease in the accuracy of identification within the usual window (the AB), but priming was still apparent in a target recall task. When subjects were not required to respond to T1, the AB was eliminated, but the amount of priming was not affected. Thus, while identification is impaired by the AB, some semantic processing still occurs in the absence of awareness.

Additional evidence of semantic processing during the AB has been obtained using behavioral and electrophysiological methods. Luck, Vogel, and Shapiro (77) recorded detection accuracy for words that were either semantically related or unrelated with the semantic context instated at the beginning of each trial, as well as a continuous EEG time locked to the presentation of the stimuli. A discrepancy between the behavioral data and averaged ERP results obtained provides evidence that the AB reflects a loss of information at a post-perceptual stage of visual processing, and that significant semantic processing can occur in a reduced attention condition.

Luck, Vogel, and Shapiro presented a stream of 20 seven-character strings, one at a time, with an ISI of 83 ms. These streams began with the presentation of a word, such as "RAZOR", or "WHEEL", (context word) which served the same purpose as a prime in a paired stimulus semantic priming task. Following this, a target appeared as either the seventh or tenth stimulus. These targets were composed of seven identical digits that were preceded by strings of random consonants rendered in blue print. The context words and filler words appeared in grey. Either one, three, or seven stimuli later, the second target appeared, in red text, which was designated the probe. At the end of each trial subjects were required to report whether the first target was composed of odd or even digits, and also whether the probe was semantically related to the context word. The context and probe words were either closely related, or unrelated. In addition, a control condition was included in which subjects were not required to search for the target.

The semantic judgement task produced accuracies of about 87, 65, and 90 percent for the one, three, and seven item lag positions, respectively. The decline in accuracy at lag position three demonstrated the effectiveness of the attentional blink manipulation, because target three appeared in precisely the time window in which attentional suppression is thought to occur. In order to analyze the ERPs created by such rapidly presented stimuli with minimal effects of stimulus overlap, difference waves were produced by subtracting waves from related trials from those produced by unrelated trials. The N400 difference waves produced when subjects searched for the target were significantly smaller than in the control condition where subjects ignored the first target. However, the effect of probe lag seen in the behavioral data was absent in the N400 for both conditions. Thus, although the N400 demonstrated that semantic processing had occurred, it was unaffected by the accompanying AB, which was evidenced by the behavioral data. (17).

Rolke, Heil, Streb, and Henninghausen (78) confirmed the presence of an N400 priming effect for words that occur during the attentional blink. In their study, subjects were presented with an RSVP task comprised of three targets printed in white amongst a stream of black distractors. A strong AB was evidenced by the 50% accuracy rate for T2 detection. They compared the ERP elicited by the second target (T2) when it was correctly identified to when it was missed. It was noted that the P300 amplitude was reduced for missed targets, which confirms the behavioral result that those T2's were not explicitly recognized. Strength of semantic association between T2 and T3 was varied over trials from not associated, to mildly associated, to strongly associated. The N400 was attenuated significantly for T3 when it was preceded by a related T2 that was correctly identified, and to a lesser, but significant extent by a T2 that was not detected correctly. Based on these findings, the authors point out that the processes responsible for N400 generation cannot account for conscious perception on their own.

A somewhat similar phenomenon that deserves mention is inattentional blindness (IB) (8), which entails a failure to perceive a supra-threshold stimulus located at or near fixation under conditions of inattention. Subjects maintain central fixation while they are presented with a distraction task in the form of a cross that appears randomly in one of the four corners of a CRT screen. The subject's task is to report which arm of the cross is longer, vertical or horizontal, while maintaining central fixation. After several trials, a stimulus is flashed at fixation for about 200 ms. This task appears to be effective at dissociating the direction of eye gaze and the focus of visual attention because the majority of stimuli presented on this critical trial go undetected by the subject.

The IB paradigm has provided evidence for semantic processing in the absence of attention in that stimuli which are consciously unreportable under conditions of IB have been shown to produce semantic priming (8). Also, in comparison with the rate at which subjects fail to detect many stimuli due to IB (geometric shapes, lines of different thicknesses and lengths, fluctuate gratings, and some linguistic stimuli) which is upwards of 90 percent, a few stimuli have been shown to have a much higher detection rate. A subject's name is more often detected and identified under controlled conditions of inattention than its physically equivalent variants. When subjects' own names were presented, only 7 out of 40 subjects failed to perceive them under conditions of inattention (12.7% failures to detect). One basic issue raised here is whether the own name effect can be due simply to the familiarity of the name. To test this, Mack and Rock (8) used the words "time and "house", which are among the most common four, and five letter concrete nouns in the English language. In this case, failure to detect was over 50%, significantly more than one's own name. Further studies by these authors used the word "the" versus "tie", with "the" being extremely common, but showing no more resistance to IB than the less common "tie". These studies made it clear that while familiarity may play a small role in resistance to IB, it is certainly not solely responsible.

Besides one's own name, an iconic representation of a happy face has been shown to be resistant to IB. The happy face consists of a circle with two dots in the "eyes" position, and an upwards turned arc in the "mouth" position. Failure to detect for this icon was only 15%, compared to 37% for a scrambled face, 60% for a sad face, and 85% for a circle with no features. When tested with an inverted happy face, failure to detect was 70 percent, showing that even with stimuli equivalent in total spatial frequency, a significant difference occurs based on the arrangement of the features.

In summary, both word and pictorial stimuli have been shown to capture attention on the basis of unique, meaning level qualities, as was demonstrated by the failure of the IB effect when simple features were altered. This finding argues for a semantic level analysis of all stimuli in the absence of attention, as indicated by near zero detection rates, and chance level identification performance under explicit testing conditions. A limitation of the paradigm is that only one critical trial may be elicited per subject. Once subjects have been explicitly questioned about the presence of a target at fixation, expectancy effects negate the power of the distractor (subjects begin checking or dividing attention) on subsequent trials. Nevertheless, the effect has been replicated on hundreds of subjects in multiple laboratories (79-80, 8).

In a related paradigm, Rees *et al*. (81) have adapted a dual-stream RSVP task to create conditions of inattention. These authors show linguistic and pictorial stimuli, drawn in red or green as overlapping line drawings, at a rate of one every 500 ms**.** The subject's task is to monitor either the word or picture stream for repeated stimuli, and to make a behavioral response when a repeat occurs. Phenomenologically, subjects report that they are aware of the presence of the unattended stream, but that they are unable to report the identity of any of the stimuli. Rees *et al*. presented their stimuli in blocks based upon type of stimulus to be attended (word-picture) and the presence or absence of real words versus orthographically legal non-words in the word stream. This blocking (lasting for about 30 seconds per block) allowed for the visualization of cerebral activity using an fMRI. The fMRI scan evidenced no differential activation for words versus non-words when they were unattended, but robust differences emerged when the linguistic stream was to be attended. Rees *et al*. suggested that semantic analysis could not have been occurring in the absence of attention because the brain areas activated by words and letter strings did not differ in the unattended condition. Rather, processing may not have progressed beyond the level of physical stimulus features.

It is possible, however, that there was no evidence of semantic activation in the unattended condition of Rees *et al*. because inhibition had dampened semantic activation. The presence of inhibition would be expected, given the findings of Deacon *et al*. (36) and Otten *et al*. which we have reviewed. Moreover the stimuli and task used in Rees *et al*. were very similar to that of Tipper and Driver (82), in which overlapping figures and words were presented in rapid succession with color as the selection cue. These authors reported strong negative priming effects for items in the to-be-ignored condition, indicating that the activation of semantic representations corresponding to the irrelevant items had been inhibited. Rees *et al*. argued that semantic activation could not have been dampened by inhibition, in their study, because negative priming does not operate under high attentional loads. Nevertheless, negative priming was demonstrated by Tipper and Driver (82) where the SOA was actually much shorter (and hence the attentional load much greater) than in the Rees *et al*. study.

6. SEMANTIC ACTIVATION WITHOUT AWARENESS

Masking paradigms may be set apart from other methods of examining automatic semantic processing, in that automaticity is insured, not by withdrawing attention, but by preventing the information from entering consciousness. Stated otherwise, the stimuli are attended, but conscious, controlled processing of the word is preempted by the mask, which renders it imperceptible, or unidentifiable. In a growing number of studies automatic semantic processing of masked words has been demonstrated by the effect of the masked prime stimulus on a subsequent target.

Critics of this literature have argued, however, that subjects may actually have have recognized stimuli that they failed to report, Several recent behavioral studies have reported data which go some distance in refuting these claims. For example, Greenwald, Klinger, and Liu (13) employed words which were masked to below the subjects recognition threshold. Greenwald and associates further refined the relative contributions of conscious and unconscious processing by applying a regression based errors-in method of data analysis to their data, and have consistently arrived at the same conclusion: unconscious semantic processing occurs even under the most stringent of methodological controls (14).

More recent work by Greenwald *et al*. has used a response window technique to look for priming effects that factor in subjects' response bias, as well as the perceptibility of the prime on a block by block basis. Greenwald, Draine, and Abrams (83) presented targets preceded either by clearly perceptible primes, or by masked primes in a between-subjects design. The targets were either names, which were to be judged "male" or "female", or emotional words, which were to be judged as having a positive or negative valence. Subjects practiced responding within a certain response window (383-517 ms post target onset), that was adjusted based on each subject's accuracy rate on the classification task. If subjects were too accurate, the window was shortened to increase the error rate, and the converse procedure was used as well. By constraining response rate, reaction time could not be used as the primary dependant measure. However, the preceding prime did exert a significant effect on the accuracy of the target classification, with congruent primes increasing accuracy. These behavioral data, transformed into the signal detection measure d',demonstrated that priming occurred, even when the prime words were imperceptible. Furthermore, by varying prime-target SOA they demonstrated that imperceptible primes produced much shorter periods of semantic activation (~100 ms), compared with perceptible primes (~400 ms). Finally, these authors compared between-trial priming effects and found that imperceptible primes did not produce between-trial priming effects, while perceptible primes did alter the degree of priming on the subsequent trial. With this study, and others performed by Greenwald which have been consistently replicated within and between research groups, it is difficult to dispute the existence of semantic activation in the absence of conscious identification.

While introducing the N400, we made reference at the beginning of this review, to three ERP studies in which words which were masked so as to prevent their identification. In concordance with the behavioral data that we have just discussed, priming effects on the N400 were observed in two of the three studies. In the remaining study the SOA used was most likely not appropriate, among other things. The circumstance that the behavioral and ERP data are largely in agreement with each other further strengthens the argument that semantic memory is indeed accessed in these paradigms, in the absence of the subjects ability to identify the words.

Evidence of semantic activation without awareness lends support to late selection theories of attention. The late selection view is that selection serves only to exclude irrelevant material from consciousness, not to curtail their processing. Critics of the late selection view have protested that such a model would not allow for any savings of controlled resources. The fact that meaning can be extracted from words in the absence of awareness, illustrates how, within a late selection framework, controlled resources could effectively be freed up even though the meanings of irrelevant words were still processed. The key here is that the semantic processing occurs outside the sphere of consciousness, thus, conscious resources can be reserved for the processing of relevant stimuli.

7. THE STROOP PARADIGM

Since the classic color-word experiment of 1935, the Stroop (84) task has allowed for the examination of the interaction between automatic and controlled processes using a wide variety of stimulus parameters (84-87). The basic paradigm involves the presentation of a list of words, and the subject is required to report the color of presentation for each word in turn. When the name of a color is presented in a discordant color ("RED" presented in black ink), it takes longer to name the color of presentation than when the color and name are concordant ("RED" presented in red ink), or neutrally related ("XXX" presented in any color of ink). The effect is attributed to the interference of the semantic processing of the word with the identification of the color name. Several mechanisms have been proposed to explain how this interference occurs, including: colors evoke a single reading response while words evoke multiple responses (88, 84), different early stimulus evaluation times (color identification versus whole word reading, with reading being faster) (89-90), stimulus-response incompatibility (91), and various theories that emphasize the mapping of stimulus codes into response codes (S-R translation) (92-94). Cohen *et al*. (95) state that while word meaning and color information may be processed in parallel, the former may influence the timing of the appropriate response based on stimulus color.

While every element of the Stroop display has been varied, from hue to spatial position, the essence of the effect appears to be semantic (See 85). Thus the most common explanation for the Stroop effect is that automatic semantic activation of the printed, task-irrelevant word interferes with the controlled color naming task (90-91) This effect is graded, such that the closer the irrelevant word is to the concept of color, the more interference is observed (92).

A series of studies varied semantic aspects of the stimuli in order to isolate the mechanisms of this interference. Warren (97-98) demonstrated that irrelevant words could produce interference if primed by previously presented associates. Since then, it has been well established that the amount of interference produced by the task irrelevant word may be increased by semantic priming (90, 97), and that semantically congruent words may produce facilitation (100-101). For example, the word "sky" will be responded to more quickly if printed in blue, as opposed to a neutral stimulus in the same color. Based on this evidence it can be argued that the Stroop task may be a special case in the general area of semantic priming paradigms in which the "prime" is the task-irrelevant word, and the "target" is the color (or other relevant stimulus dimension) of that same word. In this conception, we would expect to see automatic spreading of the semantic information in the irrelevant word act much like an associate or contextual prime in a priming task. Stroop paradigms provide strong evidence for the automaticity of semantic processing, because the semantic content of the words influences responses despite the intentions of the subjects to ignore this information and focus on color naming.

While the Stroop effect is initiated by automatically activated semantic information, several ERP studies suggest that the locus of the processing which the information interferes with may be post-lexical (102-103). The latter study reported that the latency of the P300, which reflects stimulus classification time, is unaffected by the Stroop manipulation, whereas RT is delayed in the discordant condition. Duncan-Johnson and Kopell (102) were the first to report evidence that the Stroop effect produces a P300 wave that remains stable across congruent and incongruent conditions. These authors used verbal responses which may have influenced the ERPs generated in their task. Recently, Ilan and Polich (103) replicated these findings using a manual response task to minimize response artifact. In both studies, behavioral Stroop effects were obtained showing facilitation of response times (RT) in a word-color congruent condition and inhibition of RT in an incongruent condition, relative to a neutral word-color condition. Both studies also showed that the P300 latency was unaffected by experimental condition. It was argued that the Stroop effect must occur after the processes responsible for generating the P300. The P300 was typical in that it was largest over posterior sites and declined towards the front of scalp. As the P300 is seen as an index of "stimulus evaluation time" (104), it is argued that the Stroop effect may occur in the response choice or preparation phase (85), not in the stimulus classification phase. Although never tested directly, it could be inferred from these findings that the automatic activation of the color name did not impede in any way the activation of semantic stores associated with the ink color. If interference had occurred at the level of semantic analysis, one would expect this to also be reflected at the level of stimulus classification (indexed by P300).

8. SUMMARY AND CONCLUSIONS

How have event-related potentials contributed to our understanding of automatic semantic processing, and how can the literature which we have reviewed be synthesized? First, let us consider the ERP data from the selective attention experiments which we have reviewed. The main criticism which has been raised regarding the behavioral literature on this topic is that the priming effects on ignored stimuli which have been reported may have been due to failure of selective attention or switching of attention. As we stated in the introduction, the concept of attention shifting was largely an intuitive argument, which was more applicable to the early behavioral studies, than to much of the ERP data which have been described here. The negative priming effects reported by Otten, Rugg and Doyle (50), for example, could not have been produced by a failure of selective attention. While inadvertently shifting attention to irrelevant primed stimuli might be expected to result in the usual reduction of N400s elicited by primed stimuli, it is unlikely to have manifested in the reported negative priming effects (i.e. a larger N400 to primed words) on relevant stimuli.

The priming effects obtained by Deacon *et al*. (36) on the frontal SAEs should be exempt from the attention switching criticism as well. Since the SAEs were produced by the subtraction of irrelevant trials from relevant trials, the activity associated with directing attention to the irrelevant material would have been canceled out.
The possibility of attentional shifts was considered by Kellenbach and Michie (46), and Okita and Jibu (65) in interpreting their priming effects on UA and AU stimuli, respectively. Within the context of the present review, however, it seems equally likely that their priming effects in these conditions were attributable to automatic semantic processing.

Similarly, the findings of Luck *et al*. (77) and Rolke *et al*. (78), that N400 was sensitive to priming during the AB, despite the reduced ability of subjects to respond correctly, is compatible with the view that semantic stores can be activated when attention is occupied by the preceding target. The presence of an N400 priming effect during the AB is also consistent with data showing priming effects on the N400 even though words were masked to prevent their conscious recognition (37, 38).

How can it be that N400 priming effects were apparent during the AB and the masking studies which were discussed in the Introduction, whereas, in most conditions of the selective attention studies which we have reviewed, the N400 recorded to the irrelevant words was not modulated by priming? The difference between the AB and masking studies (where N400 priming effects were obtained without awareness of the words) and selective attention studies (where no N400 priming effects were obtained) is that in the AB and masking studies subjects attempted to process the meanings of the unrecognizable words, whereas in the selective attention tasks the subjects would try not to consciously process them at all. Indeed, as we have argued, the irrelevant semantic information would have been inhibited.

As volitional semantic analysis, or at least the absence of active inhibition, seem to be a prerequisite for the occurrence of N400 priming effects, the absence of N400 priming in most selective attention studies is not surprising, and does not alone provide sufficient evidence to conclude that semantic stores were not automatically activated. This argument is bolstered by the juxtaposition within our study (36) of priming effects on the SAEs in the absence of priming effects on the N400 elicited by irrelevant items. Thus, while the data of McCarthy and Nobre (41) and Okita and Jibu (65) provide no evidence to support the notion that word meanings are processed without attention, they simultaneously provide no evidence to refute it.

The data of Kellenbach and Michie (46) , Otten, Rugg and Doyle (50), Luck *et al*. (77), Deacon *et al*. (36, 38), Schnyer *et al*.(37) and Rees *et al*. (81) collectively provide rather strong physiological evidence that semantic information is accessed even in the absence of attention. What is particularly compelling about the latter group of studies is that the data were obtained in different paradigms using different dependent measures. It is the confluence of these data, rather than any finding per se, that completes a picture of how semantic stores can be activated without attention or awareness. Part of the appeal of the argument we have offered here is its parsimony. The negative (41, 65) as well as positive findings (46, 50, 77, 36) from the selective attention studies which we have reviewed are equally consistent with our position. To reiterate, the data reviewed here have led us to conclude that semantic stores are activated in the absence of attention as well as in the absence of awareness as long as they are not deactivated by inhibition.

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