The Role of Awareness in Semantic and Syntactic Processing: An ERP Attentional Blink Study

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Abstract

■ An important question in the study of language is to what degree semantic and syntactic processes are automatic or controlled. This study employed an attentional blink (AB) paradigm to manipulate awareness in the processing of target words in order to assess automaticity in semantic and syntactic processing. In the semantic block, targets occurring both within and outside the AB period elicited an N400. However, N400 amplitude was significantly reduced during the AB period, and missed targets did not elicit an N400. In the syntactic block, ERPs to targets occurring outside the AB period revealed a late negative syntactic incongruency effect, whereas ERPs to targets occurring within the AB period showed no effect of incongruency. The semantic results support the argument that the N400 primarily indexes a controlled, postlexical process. Syntactic findings suggest that the ERP response to some syntactic violations depends on awareness and availability of attentional resources. ■

INTRODUCTION

The distinction between controlled and automatic processes is an important and enduring topic of investigation in the field of cognitive neuroscience. One of the most widely accepted models of human information processing is the two-process theory, proposed by Schneider and Shiffrin (1977) and Shiffrin and Schneider (1977). According to this theory, automatic processes are generally faster, do not use limited capacity resources, and occur without the subject's attention or control. In contrast, controlled processes are slower, use limited capacity resources, and require the conscious attention of the subject. This theory was originally applied to visual detection and search phenomena, but may be equally applicable in the study of language processing, which is also hypothesized to be mediated by both automatic and controlled mechanisms (e.g., Neely, 1991; Tartter, 1986).

A large number of behavioral priming studies have provided evidence for the importance of both automatic and controlled processes in language. The type of priming most commonly investigated is semantic priming, in which a target word is preceded by either a semantically related or unrelated prime. The typical finding is that target words are associated with faster response times and fewer errors when preceded by a semantically related prime. Neely (1991) argues that three mechanisms are needed to account for the full spectrum of priming effects seen in the literature. Automatic spread of activation (ASA) is the first mechanism. In this model, memory representations that are closely related to one another share strong links with each other within the semantic network. Activation of a given node spreads to associated representations, thereby facilitating their processing, reducing reaction times and error rates. ASA is thought to be an automatic mechanism, occurring quickly and independently of a subject's control. The second mechanism is expectancy-induced priming, which involves using a prime or preceding linguistic context to generate an expectancy set of potential targets related to the prime, thereby facilitating the processing of targets that are members of the expectancy set. Lastly, the third mechanism is postlexical priming, which refers to processes that occur after the representation of the target has been accessed. For example, the use of a compound cue consisting of both the prime and the target to access memory, rather than use of only the target itself, is one type of process theorized to contribute to this mechanism. In contrast to ASA, both expectancy-induced priming and postlexical priming are under the subjects' strategic control, are slow acting, and are thought to be controlled processes.

Electrophysiology of Language Processing

The present study was designed to investigate the contribution of automatic and controlled processes in semantic and syntactic processing. One technique that is especially well suited for studying the question of automaticity is the recording of event-related potentials (ERPs). ERPs have excellent temporal resolution and do not depend on overt behavioral responses, and thus are sensitive measures of real-time language processing. Distinct ERP components have been shown to index semantic and syntactic processing, providing evidence that these two subsystems are mediated by nonidentical neural systems.

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ERP responses to words that violate semantic expectancy are characterized by a negative-going component that peaks approximately 400 msec poststimulus, with a posterior and bilateral distribution (Kutas & Hillyard, 1980). This component is known as the N400, and its amplitude has been shown to vary as an inverse function of the subject's expectancy for the upcoming word of a sentence (Kutas & Hillyard, 1984). Words that are semantically unexpected elicit larger amplitude N400 responses than words that are more expected, given the preceding sentence context leading to the hypothesis that the N400 component reflects semantic processes of lexical integration (Friederici, Pfeifer, & Hahne, 1993; Holcomb & Neville, 1991; Kutas, Van Petten, & Besson, 1988).

In contrast, ERP components that differ in timing and distribution have been shown to index the processing of syntactic information. The hallmark pattern elicited by syntactic violations is a biphasic response (e.g., Friederici et al., 1993; Hagoort, Brown, & Groothusen, 1993; Osterhout & Holcomb, 1992; Neville, Nicol, Barss, Forster, & Garrett, 1991). The first phase consists of a negativity that is usually maximal over the left anterior scalp and that occurs during an early time window (between 100 and 500 msec), often termed the left anterior negativity (LAN). This initial waveform is followed by a late positivity, broadly distributed over posterior sites, known as the P600. One model that has been put forth postulates that these effects index distinct phases of language comprehension (Friederici, 1995, 2002). For example, the LAN may index more automatic processes associated with syntactic processing, such as the building of an initial syntactic structure based on word category information. In contrast, the P600 may reflect later, more controlled mechanisms associated with reanalysis and repair of syntactic structure, which are triggered when incoming words cannot be readily incorporated into the initially built syntactic structure (Friederici, 1995, 2002). The findings that ERP components indexing semantic and syntactic processing are distinct in both latency and distribution converge with clinical and neuroimaging evidence, showing that these subsystems are mediated by nonidentical mechanisms and draw upon at least partially dissociable neural substrates (Newman, Pancheva, Ozawa, Neville, & Ullman, 2001; Friederici, Opitz, & von Cramon, 2000; Ni et al., 2000; Goodglass, 1993). Thus, it is reasonable to propose that automatic and controlled processes may not play equal roles in semantic and syntactic processing.

ERP Studies of Automaticity in Semantic Processing

The bulk of previous ERP research assessing the relative contributions of automatic and controlled processes in language processing has used masked semantic priming paradigms, in which prime words are presented so briefly that they cannot be consciously perceived. These paradigms are designed to exclude, or at least reduce, the contribution of controlled processes. Any priming effects that occur, either behavioral or electrophysiological, are thus argued to be a result of automatic mechanisms rather than controlled strategic processes. One of the main debates to emerge from this literature is whether the N400 is indexing an automatic or controlled process of semantic processing. Studies that have used masked semantic priming paradigms have yielded mixed results. Brown and Hagoort (1993) compared the effects of both masked and unmasked presentations of a prime on the N400 and on reaction times to the target. Although reaction time data showed a significant semantic priming effect under both unmasked and masked presentations of the prime, a significant N400 effect was found only for the unmasked condition. Other authors have reported similar results, showing that the N400 effect was present for consciously perceived primes but completely disappeared when primes were masked at levels where subjects were unable to report them (Ruz, Madrid, Lupiáñez, & Tudela, 2003; Neville & Weber-Fox, 1994). Based on these results, some researchers argue that the N400 is exclusively sensitive to postlexical processes (Brown & Hagoort, 1993).

However, in contrast to these findings, a number of other studies have reported an N400 effect for masked primes (e.g., Grossi, 2006; Holcomb, Reder, Misra, & Grainger, 2005; Kiefer, 2002; Deacon, Hewitt, Yang, & Nagata, 2000). Even among those authors who report a similar N400 effect to masked primes, interpretations of these results may differ. For example, Deacon et al. (2000) interpret their finding of an N400 masked priming effect as evidence that the process reflected by the N400 effect cannot reflect any postlexical mechanisms, because subjects were not able to consciously perceive the stimuli, and is thus exclusively automatic. However, other authors have argued that the presence of a masked priming effect on the N400 indicates only that the N400 is *sensitive* to the influence of automatic priming (Holcomb et al., 2005). That is, the N400 can be influenced by automatically established contexts such as those provided by a masked prime, but still directly indexes postlexical mechanisms that require attention to the semantic properties of the target word. To provide stronger support for the contention that the N400 is a direct reflection of automatic processing, the authors argue that it would be necessary to show an N400 effect when participants are unaware of and unable to identify target words, rather than the prime words. On the other hand, if the ERPs to nonreportable targets fail to show N400 priming effects, this would provide strong evidence that the N400 does not directly reflect an automatic process. Thus, manipulating awareness of the target and comparing ERP effects elicited by targets that have and have not reached awareness would represent a convincing test of whether or not the N400 process is automatic. More precisely, this manipulation could reveal whether automatic mechanisms, such as ASA, or more controlled, strategic processes, such as expectancy-induced priming or postlexical priming, play a major role in generating the N400, contributing to our understanding of the linguistic processes underlying this component.

One previous study has investigated whether there is evidence of a priming effect on the N400 when targets are masked (Stenberg, Lindgren, Johansson, Olsson, & Rosen, 2000). In that study, category labels were shown to participants, followed by masked words that either were or were not exemplars of the category. Exposure durations were varied to allow for identification in approximately half the trials. Unidentified targets elicited a small yet significant N400 effect, suggesting that the N400 may be indexing at least a partially automatic processes. However, one limitation of this study is that it used a range of exposure durations, and that targets were far more likely to be reported during the longest durations. Therefore, it is possible that long-duration targets made most or all of the contribution to the N400, and that the obtained effects were not actually due to unconscious processing (Holcomb et al. 2005).

The attentional blink (AB) paradigm is an alternative method of manipulating the awareness of the target, which circumvents this problem of unequal exposure durations being binned together. The AB is a phenomenon that is observed when two targets occur in close proximity to one another in a rapid serial visual presentation (RSVP) stream (Raymond, Shapiro, & Arnell, 1992; Broadbent & Broadbent, 1987). Although subjects are able to report the first target (T1) with high accuracy, they show a marked decrease in accuracy in reporting the second target (T2) when it occurs between 200 and 500 msec after the first target. This interval of time is known as the AB period. When T2 is separated by a sufficient period of time from the first target (>500 msec), T2 report recovers to a relatively high level of accuracy. Although several different models have been proposed to account for the AB, the distinction between two stages of processing is common to most models (Giesbrecht & Di Lollo, 1998; Jolicoeur & Dell'Acqua, 1998; Vogel, Luck, & Shapiro, 1998; Shapiro, Arnell, & Raymond, 1997; Chun & Potter, 1995; see Nieuwenstein, Chun, van der Lubbe, & Hooge, 2005). The first stage is a high-capacity early stage, in which representations of the RSVP items give rise to short-lived memory traces that are easily overwritten by items that subsequently enter this stage. The ability to report items from the RSVP stream depends upon whether they are admitted to the second stage of processing, which is severely limited in capacity but represents a more durable form of short-term memory. According to many models, the AB occurs because the attentional response to T2 is delayed by T1 processing, causing T2 to lose a competition for attention to the item that follows it. Thus, by preventing T2 from reaching the subject's awareness during the critical AB period, the AB paradigm offers an effective experimental manipulation by which the role of automatic mechanisms can be assessed.

Several previous studies have used the AB paradigm to investigate whether the N400 effect is modulated when the eliciting stimulus is less likely to be available for explicit report. Vogel et al. (1998; see also Luck, Vogel, & Shapiro, 1996) were the first group to investigate semantic processing using this approach. Despite a marked decrease in subjects' ability to report T2 during the AB period, there was no evidence of N400 suppression during this time. The authors interpreted this finding as evidence that the T2 word was identified to the point of meaning extraction, even when subjects were unable to report this word 1 to 2 sec later, and that the AB reflects a loss of information that occurs after the stage of semantic identification has occurred. In other words, according to this account, the processing of semantic information may be thought of as a more automatic process, occurring before the target reaches awareness and becomes available for explicit report. These findings were recently extended by Giesbrecht, Sy, and Elliott (2007). The authors showed that no N400 suppression occurred during the AB period when perceptual load of T1 was low, replicating Vogel et al.'s results, but found a nearly complete reduction of the N400 effect when the perceptual load of T1 was high. These results were taken as evidence that attention can act to select information at multiple stages of processing. Depending on concurrent task demands, either perceptual or postperceptual selection can occur during the AB, and word meanings may or may not be accessed during the AB. However, neither of these studies directly addressed the role of awareness in generating the N400, as neither compared the N400 response to correctly reported targets to that generated by missed targets.

Another AB study, by Rolke, Heil, Streb, and Hennighausen (2001), presented three targets words in an RSVP stream and varied the association strength between the second target (the prime) and the third target (the probe). The experiment was set up so that the prime occurred during the AB period, and thus, subjects' ability to report it was substantially reduced. The authors found an N400 effect to probes that were preceded by reported as well as missed primes, although the effect was somewhat attenuated when primes were missed. This finding was given as evidence that automatic mechanisms, specifically ASA, are sufficient to evoke the N400 effect. A fourth study used a very similar design, embedding three targets within an RSVP stream so that the prime occurred during the AB period. However, unlike Rolke et al. (2001), these authors found an N400 effect only when the prime was reported, and not when it was missed (Pesciarelli et al., 2007). One possible explanation for these inconsistent results, suggested by Pesciarelli et al. (2007), is that Rolke et al.'s study used a small number of prime words that were often repeated, which may have increased the resting level of the primes, supporting priming mechanisms even when these words were not explicitly recognized. Thus, it remains unclear whether or not awareness of the prime in an AB context is necessary to generate the N400. In addition, interpretation of these two studies is limited by the same line of reasoning that constrains masked priming studies, as discussed by Holcomb et al. (2005). That is, subjects were aware of the target, and thus, the N400 may still have directly reflected postlexical mechanisms that, although sensitive to the effects of automatic priming, require attention to the semantic properties of the target word. Thus, like masked priming studies, the three-target AB paradigm has been inconclusive in addressing the role of automatic mechanisms and awareness on the N400.

ERP Studies of Automaticity in Syntactic Processing

As is evident from the previous discussion, most masked priming and AB studies of language processing have been carried out in the semantic domain. By contrast, very little is known about syntactic processing without awareness. All syntactic priming studies have used *unmasked* primes, and only a small number of these studies have been carried out. One of the first studies to investigate the effects of the syntactic priming used a single prime word, either an article or pronoun, which strongly predicted the word category (noun or verb) of the following word. The authors reported that syntactically appropriate prime words reduced reaction time in a lexical decision task for subsequent targets by 19 msec, a small but significant decrease (Goodman, McClelland, & Gibbs, 1981). This finding of a small but reliable behavioral syntactic priming effect has been confirmed by a number of subsequent studies using similar word category priming procedures (Sereno, 1991; Seidenberg, Waters, Sanders, & Langer, 1984; Wright & Garrett, 1984). Thus, there is some evidence to suggest that a syntactically congruent context, given by appropriate word category information, facilitates the processing of subsequent targets.

Only one previous study has used a similar word category priming paradigm to compare the ERP response to targets preceded by syntactically appropriate versus inappropriate primes (Münte, Heinze, & Mangun, 1993). In that study, subjects were asked to judge as quickly as possible whether each word pair constituted a syntactically correct phrase. The researchers replicated the syntactic behavioral priming effect, reporting that valid pairs elicited a faster response than invalid pairs. In addition, they also reported that targets preceded by syntactically incongruent primes elicited a late negative ERP response relative to syntactically congruent targets. This negativity was maximal between 400 and 600 msec poststimulus onset and had a left frontal scalp maximum. The study also included a semantic condition, in which subjects judged whether the target word was synonymous with the prime word. This task elicited a typical N400 component with an earlier latency and more central, posterior distribution. The authors interpreted these results as evidence that syntactic aspects of language processing are dissociable from the semantic processes indexed by the N400, and that these two processes are generated by nonidentical neural substrates. The results of this study also suggest that word category violations in an impoverished (i.e., nonsentential) syntactic context do not elicit the typical biphasic response observed in sentence contexts, but rather a late negative response.

Despite the findings yielded by this handful of studies, syntactic (or more specifically, word category) priming has not been extensively studied, and much less is known about syntactic priming than semantic priming. Furthermore, no ERP studies of automaticity in syntactic processing using a priming paradigm have been carried out.

The Present Study

The goal of the present study was to investigate the roles of automatic and controlled processes in both semantic and syntactic processing. The AB is an experimental manipulation well suited to this purpose. By comparing ERP components to semantic and syntactic targets occurring during the AB period with those occurring outside the AB period, it is possible to make inferences about the effects of awareness on the processing of target words. By further separating correct trials from incorrect trials in both AB conditions, more precise comparisons of ERPs elicited by reported and missed words can be made, and more direct conclusions about the effects of awareness on semantic and syntactic processing can be drawn.

If the N400 indexes a purely automatic mechanism and does not reflect any postlexical conscious processes, as some researchers have suggested (i.e., Deacon et al., 2000), there should be no evidence of N400 suppression in the semantic condition for target words presented during the AB period compared to targets presented outside the AB period. This finding would be consistent with two previous reports in the AB literature (Giesbrecht et al., 2007; Vogel et al., 1998). Furthermore, separate examinations of correct and incorrect targets should reveal no difference in N400 amplitude between the correct and incorrect trials. In contrast, if the N400 is a direct reflection of controlled, postlexical mechanisms, as other researchers have proposed (i.e., Holcomb et al., 2005), a suppressed N400 effect for targets occurring within the AB period compared to targets presented outside the AB period would be expected, reflecting the higher percentage of targets during the AB period that did not reach the level of awareness and become available for controlled processing. In addition, there should be no evidence of an N400 effect when looking at incorrect trials alone because presumably none of these targets would have reached the postlexical stage of processing.

Because there have not been any previous studies to examine the ERP effect elicited by word category violations in an AB paradigm, the syntactic condition in this study was somewhat more exploratory than the semantic condition. Perhaps the most comparable study to date is that by Münte et al. (1993), who, as discussed previously, reported that target words preceded by unmasked incongruent primes elicited a late negative response. If this finding holds under an AB manipulation, similar ERP effects in our paradigm might be expected. Following the same line of reasoning that guided hypotheses in the semantic condition, if this late negative effect indexes an automatic process, a similar response to targets presented both within and outside the AB period should be found. In addition, when separating correctly reported trials from incorrectly reported trials, similar ERP effects should be revealed regardless of whether the target was correctly reported. In contrast, if this late negativity reflects a more controlled process, there should be a larger effect to targets that occur outside the AB period compared to targets presented within the AB period. Furthermore, this ERP response should be eliminated in trials where the target was not correctly reported.

METHODS

Participants

Twenty-one monolingual native English speakers (14 women) were recruited at the University of Oregon to participate in the experiment. Participants were between 18 and 30 years old ($M = 23.3$, $SD = 3.49$), were right-handed, had no history of neurological problems, and had normal or corrected-to-normal vision. They were paid $10/hour for their participation.

Stimuli

Both the semantic and syntactic conditions followed a paradigm similar to the one used by Vogel et al. (1998). As illustrated in Figure 1, each trial began with the presentation of a prime word for 1000 msec, followed by a blank interval for 1000 msec. An RSVP stream was then presented, consisting of seven-character strings of letters that were presented for 83 msec each. T1, which consisted of a randomly selected number (between 2 and 9) written out in letters and flanked by Xs to create a seven-character string, occurred randomly between positions five through eight. T2 was a word three to seven characters long, flanked by pound signs (#) if the word contained fewer than seven characters to create a seven-character string. The T2 word occurred either 3 or 10 positions after T1 (i.e., Lag 3 or Lag 10). Distractors were composed of seven-character strings consisting of randomly selected consonants. All distractor items were presented in blue, and both T1 and T2 were presented in red.

Based on a simple computer algorithm designed to maximize the AB effect, the blue distractor color was adjusted at regular intervals throughout the experiment depending upon subject performance. Within each lag condition, percent accuracy was calculated every eight trials. If subjects correctly reported six or more T2 words in Lag 3, the blue distractor color was adjusted to become darker, increasing the overall difficulty. If subjects incorrectly reported two or more T2 words in Lag 10, the blue distractor color became lighter, making the task easier (beginning RGB value = 0, 100, 255; mean final RGB value in semantic block = 0, 0, 255; mean final RGB value in syntactic block = 0, 75, 255). A 1000-msec blank interval followed

A

Stimulus Type	Time (msec)	Related Trial	Unrelated Trial
Context Word	1000	DOCTOR	CUP
Blank	1000		
Distractor	83	WLDKFWR	JRFGJHT
Distractor	83	SPQRTRX	PNBVCZW
Distractor	83	DLKMSFW	WYTRQSX
Distractor	83	JPYTWRZ	PJHGTMB
Distractor	83	MNBVCRP	WRTGHFD
Distractor	83	KHJDWYT	SCVNMXP
T1	83	**XTHREEX**	**XXNINEX**
Distractor	83	WPKCXTY	PLTRWCV
Distractor	83	SQWKHFV	ZPLJHFR
T2	83	**#NURSE#**	**#KITTEN**
Distractor	83	PYLMBXC	WQPLFDS
Distractor	83	ZTNBGFD	DCMPLTF
Distractor	83	SDFKLHM	CPTRWQF
Distractor	83	PMYTNBC	XCDFGTH
Distractor	83	LPYTKHD	PJKHTGB
Distractor	83	GJKMNLB	WSTRDPL
Distractor	83	BVCPLMB	PMBVCZT
Distractor	83	WRTHGFX	WRTJKGD
Distractor	83	ZXVCNPH	PPKTRVD
Distractor	83	WRHKJFJ	WKHSDGB
Distractor	83	PLMBCSW	XNMVBNR
Distractor	83	RTLKMCZ	HNKTMBW
Distractor	83	PLYGHKN	MBLPTJG

B

Stimulus Type	Time (msec)	Congruent Trial	Incongruent Trial
Context Word	1000	THE	MY
Blank	1000		
Distractor	83	WLDKFWR	JRFGJHT
Distractor	83	SPQRTRX	PNBVCZW
Distractor	83	DLKMSFW	WYTRQSX
Distractor	83	JPYTWRZ	PJHGTMB
Distractor	83	MNBVCRP	WRTGHFD
Distractor	83	KHJDWYT	SCVNMXP
T1	83	**XTHREEX**	**XXNINEX**
Distractor	83	WPKCXTY	PLTRWCV
Distractor	83	SQWKHFV	ZPLJHFR
T2	83	**#WAGON#**	**#ACCEPT**
Distractor	83	PYLMBXC	WQPLFDS
Distractor	83	ZTNBGFD	DCMPLTF
Distractor	83	SDFKLHM	CPTRWQF
Distractor	83	PMYTNBC	XCDFGTH
Distractor	83	LPYTKHD	PJKHTGB
Distractor	83	GJKMNLB	WSTRDPL
Distractor	83	BVCPLMB	PMBVCZT
Distractor	83	WRTHGFX	WRTJKGD
Distractor	83	ZXVCNPH	PPKTRVD
Distractor	83	WRHKJFJ	WKHSDGB
Distractor	83	PLMBCSW	XNMVBNR
Distractor	83	RTLKMCZ	HNKTMBW
Distractor	83	PLYGHKN	MBLPTJG

Figure 1. Example stimuli from the (A) semantic and (B) syntactic blocks.

the RSVP stream, which was then followed by the response period.

In the semantic block, T2 was semantically related to the prime word (e.g., *dog–puppy*) on half the trials. On the other half of trials, T2 was not semantically related to the prime word (e.g., *lemon–puppy*). One hundred twenty semantically related word pairs were selected randomly from a pool of 360 highly related word pairs (Postman & Keppel, 1970) and were the same stimulus pairs used by Vogel et al. (1998). Target words in unrelated word pairs were identical to those in related word pairs. Unrelated word pairs were created by randomly combining these target words with primes from the remaining 220 word pairs. For each subject, word pairs appeared in random order, assigned randomly to either the Lag 3 or Lag 10 condition, and were counterbalanced so that each target appeared once in both the related and unrelated conditions. Thus, the same words were presented as targets in both the related and unrelated conditions, ensuring that the target words were matched on all dimensions. There were a total of 240 trials in the semantic block, with 60 trials in each Relatedness by Lag cell.

In the syntactic block, the prime word correctly predicted the word category of T2 on half the trials (e.g., *the–sky*), while incorrectly predicting word category information of T2 on the other half of the trials (e.g., *we–sky*). Primes were chosen from the following six words: *the*, *her*, and *my* (articles and possessive pronouns), which strongly predict a noun for the following word, and *we*, *you*, and *I* (nominative pronouns), which strongly predict that a verb will follow as the next word. Target words were chosen to belong unambiguously to either the noun or verb category. A total of 80 nouns and 80 verbs were selected as targets. All target words were between three and six letters in length, and nouns and verbs were matched for frequency and length using the Kucera–Francis database. As in the semantic block, word pairs appeared in random order and were counterbalanced so that all targets appeared once in both the congruent and incongruent conditions. Thus, a total of 320 trials were presented in the syntactic block, with 40 trials in each Congruency by Word class (noun, verb) by Lag cell.

The stimuli were presented against a gray background on a computer monitor placed approximately 140 cm from the participant. The visual angle of words subtended 3.5° horizontally and 0.5° vertically.

Procedure

Before the ERP experiment, participants gave written consent and filled out a brief demographic questionnaire designed to ensure they met all inclusion criteria. After application of an elastic EEG cap embedded with electrodes, participants were seated in a comfortable chair in a dimly lit, acoustically and electrically shielded booth. They were instructed to identify the two red targets in the RSVP stream and to make two alternative forced-choice responses using a game controller at the end of each trial. In the semantic block, these responses indicated whether the number (T1) was odd or even, and whether the word (T2) was semantically related or unrelated to the prime word that appeared at the beginning of the trial. In the syntactic block, participants were again asked to decide whether the number was odd or even, and whether or not the word made a syntactically congruent phrase with the preceding prime word. After participants entered their responses, the next trial began automatically after a brief interval. Subjects were given as much time as needed to respond, but generally responded within 1 to 2 sec after the cue appeared. Before each block, participants were given approximately 10 to 20 practice trials. Once the experiment was underway, participants were given brief breaks every 60 trials. All subjects participated in both the semantic and syntactic blocks, which appeared in counterbalanced order across participants.

ERP Recording and Analysis

EEG activity was recorded from 29 tin electrodes mounted in an elastic cap (Electro-Cap International, Eaton, OH). The electrooculogram was recorded from electrodes placed at the outer canthi of both eyes and below the right eye. Scalp electrodes were referenced to the right mastoid during recording and for off-line averaging. The EEG was amplified with a bandpass of 0.01–100 Hz and digitized at a sampling rate of 250 Hz.

ERP analyses were carried out using EEGLAB (Delorme & Makeig, 2004). First, trials containing large or paroxysmal artifacts, movement artifacts, or amplifier saturation were identified by visual inspection and removed from further analysis. Data were then submitted to the extended runica routine of EEGLAB software. Ocular artifacts were identified from scalp topographies and the component time series and were removed. ICA-cleaned data were subjected to a final manual artifact correction step to detect any residual or atypical ocular artifacts not removed completely with ICA. For eight subjects, ICA did not converge on clean ocular artifact components due to low numbers of vertical or horizontal eye movements or blinks. For these data, ocular artifacts were detected and removed manually by inspecting eye channels for deflections and polarity inversions with scalp channels. The epochs were averaged to the onset of the T2 word, with a 100-msec prestimulus baseline. To maximize any possible AB effects, both behavioral and ERP analyses included only those trials on which T1 was correctly reported.

Time windows for measuring the semantic and syntactic ERPs were selected based on visual inspection of the waveforms. Because both effects persisted to the end of the averaging epoch (1000 msec) in both conditions, two time windows were selected to capture the earlier and later parts of the effect. However, effects were more robust in the earlier time window, and thus, analyses from the later time window will not be reported. In the semantic condition, the N400 effect was measured as the difference in mean amplitude between related and unrelated targets in the 350–550 msec poststimulus time window. In the syntactic condition, the congruency effect was measured as the difference in mean amplitude between congruent and incongruent targets in the 500–700 msec poststimulus time window. For the analyses of congruency effects, repeated measures analyses of variance (ANOVAs) were conducted separately for each block (semantic and syntactic) with five factors (lag [Lag 10, Lag 3], congruency [congruent, incongruent], hemisphere [left, right], anterior/posterior [frontal, fronto-temporal, temporal, central, parietal, occipital], and laterality [lateral, medial]). To visualize the effects of lag on the congruency effect for each block, difference waves were constructed by subtracting the ERP waveforms elicited in the congruent condition from those in the incongruent condition. Finally, to carefully compare the distribution of the semantic and syntactic congruency effects, these difference waves were normalized by the following procedure recommended by McCarthy and Wood (1985): The grand mean amplitude and standard deviation of all the electrode sites and all the participants were computed for each condition. The grand mean amplitude was subtracted from the amplitude at each electrode site for each participant, and the difference was divided by the standard deviation. A repeated measures ANOVA was then carried out on the normalized data, within each paradigm's respective time windows, with type [semantic, syntactic], hemisphere, anterior/posterior, and laterality as factors.

Separate analyses of correctly and incorrectly reported T2 words were also performed to examine the effect of awareness on ERP response more directly. Using the same time windows as previously described, a repeated measures ANOVA with six factors (correctness [correct, incorrect], lag, congruency, hemisphere, anterior/posterior, and laterality) was carried out for each block (semantic and syntactic). For each congruency type, correctness, and lag (Semantic Correct Lag 10, Semantic Incorrect Lag 10, Semantic Correct Lag 3, Semantic Incorrect Lag 3, Syntactic Correct Lag 10, Syntactic Incorrect Lag 10, Syntactic Correct Lag 3, Syntactic Incorrect Lag 3), separate average waveforms were created to visualize the effects.

Lastly, midline analyses were carried out using repeated measures ANOVAs with relatedness/congruency and site (Fz, Cz, and Pz) as factors. The results of these analyses are reported where relevant. For all analyses, Greenhouse–Geisser corrections were reported for factors with more than two levels.

RESULTS

Behavioral Results

Mean T2 discrimination for both the semantic and syntactic blocks is plotted as a function of T2 lag in Figure 2. In both semantic and syntactic paradigms, there was a substantial decrease in accuracy for Lag 3 compared to Lag 10 [semantic: $F(1, 20) = 49.98$, $p < .001$; syntactic: $F(1, 20) = 37.83$, $p < .001$], which is indicative of a significant AB effect. There was no significant effect of relatedness on T2 accuracy in the semantic block [$F(1, 20) = 0.61$, $p = .44$]. In contrast, the effect of congruency in the syntactic block was significant [$F(1, 20) = 6.57$, $p = .019$], such that congruent targets were more accurately reported than incongruent targets. The mean accuracy for T1 discrimination in the semantic paradigm was 86.1% (*SE* = 1.56%) and in the syntactic paradigm was 88.0% (*SE* = 1.63%). Participants showed significantly higher T2 accuracy in the semantic block than in the syntactic block [$F(1, 20) = 20.56$, $p < .001$]. There was no difference in T1 accuracy between blocks [$F(1, 20) = 1.21$, $p = .284$].

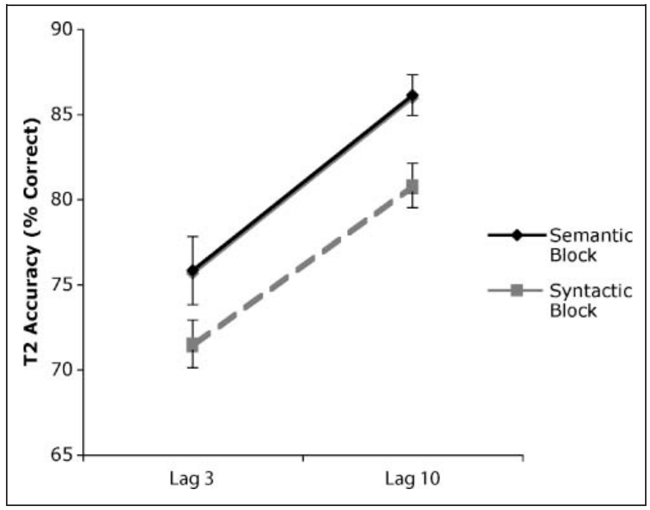

Figure 2. Mean discrimination accuracy for the second target (T2) word as a function of lag, in both the semantic and syntactic blocks. Error bars represent standard error.

ERP Results: Semantic Block

All Trials

Visual inspection of the grand-average ERPs indicated that there was an N400 effect at Lag 10 as well as at Lag 3, as shown in Figure 3. In both cases, this effect onset at approximately 300 msec poststimulus and continued to the end of the epoch.

Across lags during the 350–550 msec time window, the ERPs elicited by unrelated T2 target words were more negative compared to the ERP response elicited by related T2 target words, indicative of a significant N400 effect [relatedness: $F(1, 20) = 23.5$, $p < .001$]. As can be seen in the mean amplitude plots (Figure 4) and difference waves (Figure 3), the N400 effect was significantly reduced at Lag 3 relative to Lag 10 [Lag × Relatedness: $F(1, 20) = 4.67$, $p = .043$]. The reduction in this effect was most pronounced over medial and posterior medial sites [Lag × Relatedness × Laterality: $F(1, 20) = 5.26$, $p = .033$; Lag × Relatedness × Anterior/Posterior × Laterality: $F(5, 100) = 2.41$, $p = .084$].

Follow-up analyses revealed that the N400 effect remained significant within each lag condition [Lag 10: $F(1, 20) = 19.66$, $p < .001$; Lag 3: $F(1, 20) = 13.48$, $p = .002$; Figure 3]. The distribution of the N400 effect was larger over posterior and medial sites at both Lag 10 [Relatedness × Anterior/Posterior: $F(5, 100) = 9.29$, $p = .001$; Relatedness × Laterality: $F(1, 20) = 15.32$, $p = .001$; Relatedness × Anterior/Posterior × Laterality: $F(5, 100) = 8.87$, $p < .001$] and Lag 3 [Relatedness × Laterality: $F(1, 20) = 6.42$, $p = .020$; Relatedness × Anterior/Posterior × Laterality: $F(5, 100) = 4.86$, $p = .001$].

Correct versus Incorrect Trials

Across lags, the N400 effect was significantly reduced for incorrect trials relative to correct trials [Correctness × Relatedness: $F(1, 19) = 18.00$, $p < .001$]. The N400 reduction

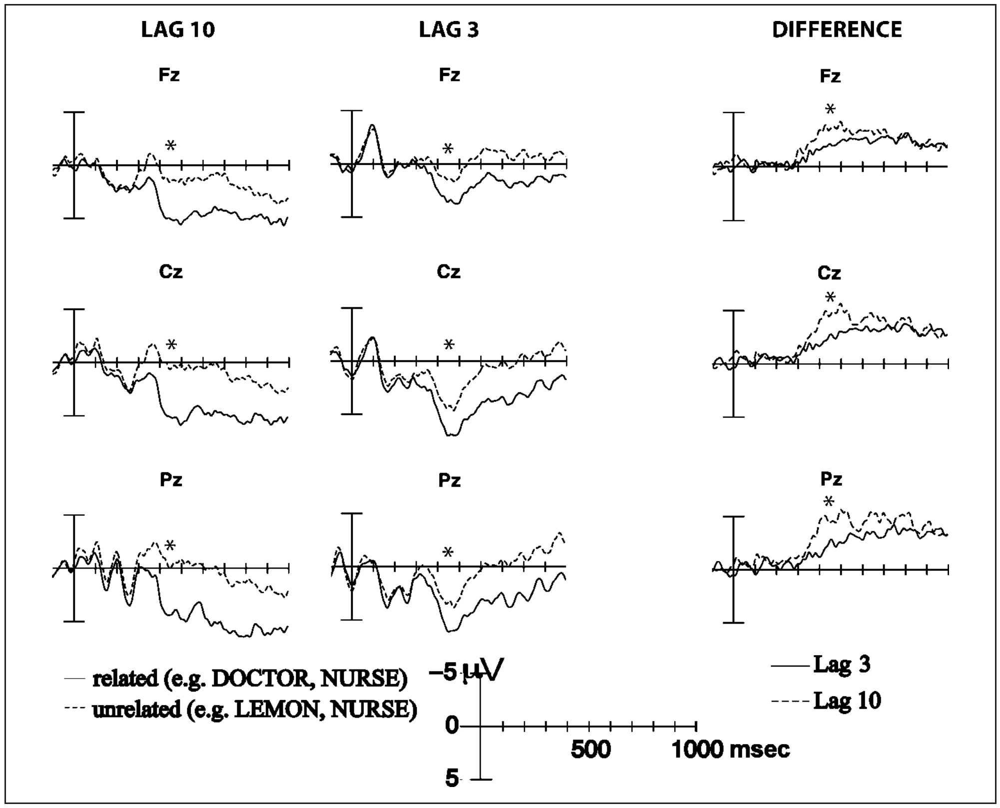

Figure 3. Grand-average ERP waveforms at midline sites to the second target (T2) in the semantic block, for all trials. Lag 10 targets are shown on the left, Lag 3 targets are shown in the middle, and difference waves, formed by subtracting related T2 trials from unrelated T2 trials, are shown on the right. The first two columns show related and unrelated trials, whereas the last column shows Lag 3 and Lag 10 trials.

for incorrect trials was largest over medial and posterior medial sites [Correctness × Relatedness × Laterality: $F(1, 19) = 7.10, p = .015$; Correctness × Relatedness × Anterior/Posterior × Laterality: $F(5, 95)=7.26, p = .026$].

The reduction in the relatedness effect for incorrect trials showed a different pattern at each lag. At Lag 3, the N400 was reduced for incorrect trials, although in the same direction, whereas at Lag 10, the relatedness effect was opposite in polarity [Correctness × Relatedness × Lag: $F(1, 19) = 10.48, p = .004$; Figure 5]. The reduction of the relatedness effect was largest over posterior sites at Lag 10 and largest over anterior sites at Lag 3 [Correctness × Relatedness × Lag × Anterior/Posterior: $F(5, 95) = 8.775, p = .002$].

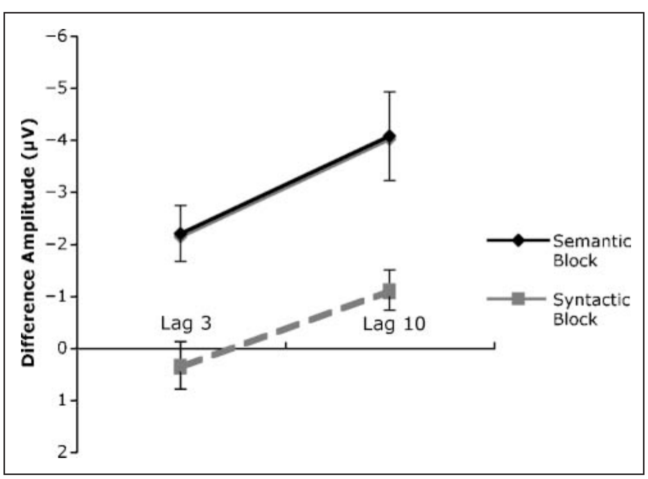

Figure 4. Mean amplitude plots for the semantic block and the syntactic block as a function of lag, averaged across midline scalp sites (Fz, Cz, and Pz). Mean amplitude for the semantic block was computed during 350–550 msec time window, and mean amplitude for the syntactic block was computed during the 500–700 msec time window. Negative is plotted upward.

Follow-up analyses indicated that there was a significant N400 effect for correct trials at Lag 10 [relatedness: $F(1, 20) = 21.04, p < .001$; Figure 5]. This N400 effect had a medial posterior distribution similar to the one described for the overall average at Lag 10 [Relatedness × Anterior/Posterior: $F(5, 100) = 9.52, p = .001$; Relatedness × Laterality: $F(1, 20) = 15.05, p = .001$; Relatedness × Anterior/Posterior × Laterality: $F(5, 100) = 10.20, p < .001$]. Similarly, for correct trials at Lag 3, we again found a significant N400 effect [relatedness: $F(1, 20) = 13.73, p = .001$]. Similar to previously described distributions, the effect was largest medially and posteriorly [Relatedness × Anterior/Posterior: $F(5, 100) = 5.85, p = .003$; Relatedness × Laterality: $F(1, 20) = 7.54, p = .012$].

For the incorrect trials at Lag 10, a significant relatedness effect that was opposite in polarity to the N400 was found during the 350–550 msec time window [relatedness: $F(1, 19) = 6.27, p = .022$; Figure 5]. This effect did not interact significantly with any electrode site.

In contrast, the incorrect trials at Lag 3 did not show a main effect of relatedness [$F(1, 20) = 0.452, p = .509$; Figure 5]. A significant Relatedness × Anterior/Posterior interaction was found [$F(5, 100) = 4.20, p = .043$], indicating that the difference between unrelated and related targets

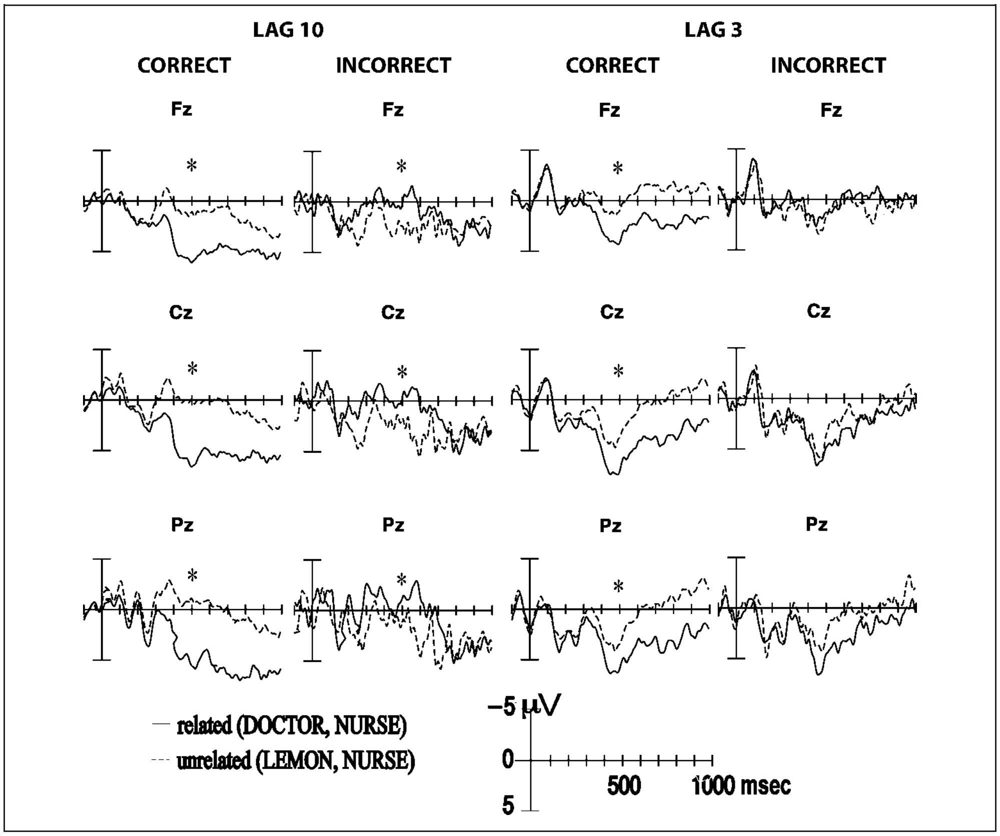

Figure 5. Grand-average ERP waveforms showing ERPs to correctly reported and missed trials in the semantic block for each lag condition at midline sites.

was largest at parietal and occipital sites. However, follow-up analyses confined to electrodes in the parietal and occipital scalp regions (T5, P3, P4, T6, TO1, O1, O2, TO2) showed that this relatedness effect was not reliable [relatedness: $F(1, 20) = 2.05, p = .168$]. Similarly, an analysis of midline electrodes indicated that there was no significant relatedness effect at any site [relatedness: $F(1, 20) = 0.40, p = .537$]. Thus, there was no evidence of a reliable N400 effect to targets that were missed during the AB.

As evident in the difference waves for the correct trials (Figure 6), Lag 10 targets elicited a significantly larger N400 effect than Lag 3 targets [lag: $F(1, 20) = 5.23, p = .033$]. This effect was largest at posterior sites [Lag × Anterior/Posterior: $F(5, 100) = 4.183, p = .038$] and also tended to be larger medially [Lag × Laterality: $F(1, 20) = 3.70, p = .069$]. However, for the incorrect trials, also displayed in Figure 6, no reliable N400 was observed, but a main effect of lag [$F(1, 19) = 6.64, p = .018$] indicates that the Lag 10 relatedness effect was significantly more *positive* than the Lag 3 effect. This lag effect was larger over posterior electrode sites [Lag × Anterior/Posterior: $F(5, 95) = 4.12, p = .039$].

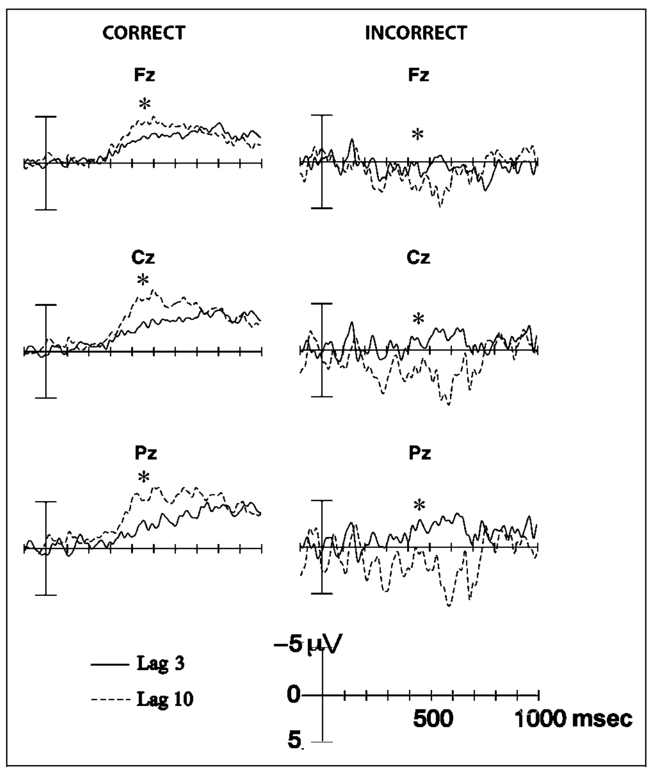

Figure 6. Difference waves, formed by subtracting related T2 trials from unrelated T2 trials in the semantic block, for correctly reported and missed trials, by lag condition. Correctly reported trials are shown in the left column and incorrectly reported trials are shown in the right column.

ERP Results: Syntactic Block

All Trials

Visual inspection of the ERP grand average indicated that there was a late negative congruency effect at Lag 10, with incongruent targets evoking more negative ERPs than congruent targets. This effect onset at approximately 500 msec poststimulus and lasted for the duration of the epoch. In contrast, at Lag 3, incongruent targets elicited more positive ERPs than congruent targets between approximately 400 and 700 msec poststimulus, although this difference appeared to be very small. These effects, along with their corresponding difference waves, are displayed in Figure 7.

There was no main effect of congruency across lags during the 500–700 msec time window [congruency: $F(1, 20) = 0.26$, $p = .62$]. However, as can be seen in the mean amplitude plots (Figure 4) and the difference waves (Figure 7), the congruency effect was significantly more negative at Lag 10 than at Lag 3 [Lag × Congruency: $F(1, 20) = 5.77$, $p = .026$]. This difference was largest over medial sites [Lag × Congruency × Laterality: $F(1, 20) = 8.57$, $p = .008$].

Follow-up analyses revealed that incongruent targets elicited a negative ERP response relative to congruent targets at Lag 10, representing a significant congruency effect [$F(1, 20) = 4.89$, $p = .039$]. This effect was largest over medial sites [Congruency × Laterality: $F(1, 20) = 14.21$, $p = .001$]. In contrast, no main congruency effect was found at Lag 3 [$F(1, 20) = 2.17$, $p = .156$]. At Lag 3, a significant Congruency × Hemisphere × Laterality interaction was revealed [$F(1, 20) = 6.46$, $p = .019$], suggesting that the effect of congruency was greatest at right lateral and left medial sites. However, follow-up analyses confined to these sites (F8, FT8, T4, CT6, T6, T02, F3, FC5, C5, C3, P3, and O1) indicated that the congruency effect was not significant [$F(1, 20) = 2.72$, $p = .115$]. Therefore, there was no evidence of a reliable syntactic congruency effect during the AB period.

Correct versus Incorrect Trials

During the 500–700 msec time window, although there was no overall effect of correctness on the congruency effect [Correctness × Congruency: $F(1, 20) = 0.55$, $p = .47$], a significant Correctness × Congruency × Laterality interaction was found [$F(1, 20) = 12.98$, $p = .002$], as well as a significant Correctness × Congruency × Hemisphere × Anterior/Posterior interaction [$F(5, 100) = 3.73$, $p = .012$] and a marginally significant Correctness × Congruency × Anterior/Posterior × Laterality interaction [$F(5, 100) = 2.21$, $p = .093$]. These results suggested that the difference in the congruency effect between correct and incorrect trials was greater at medial, posterior, and right hemisphere

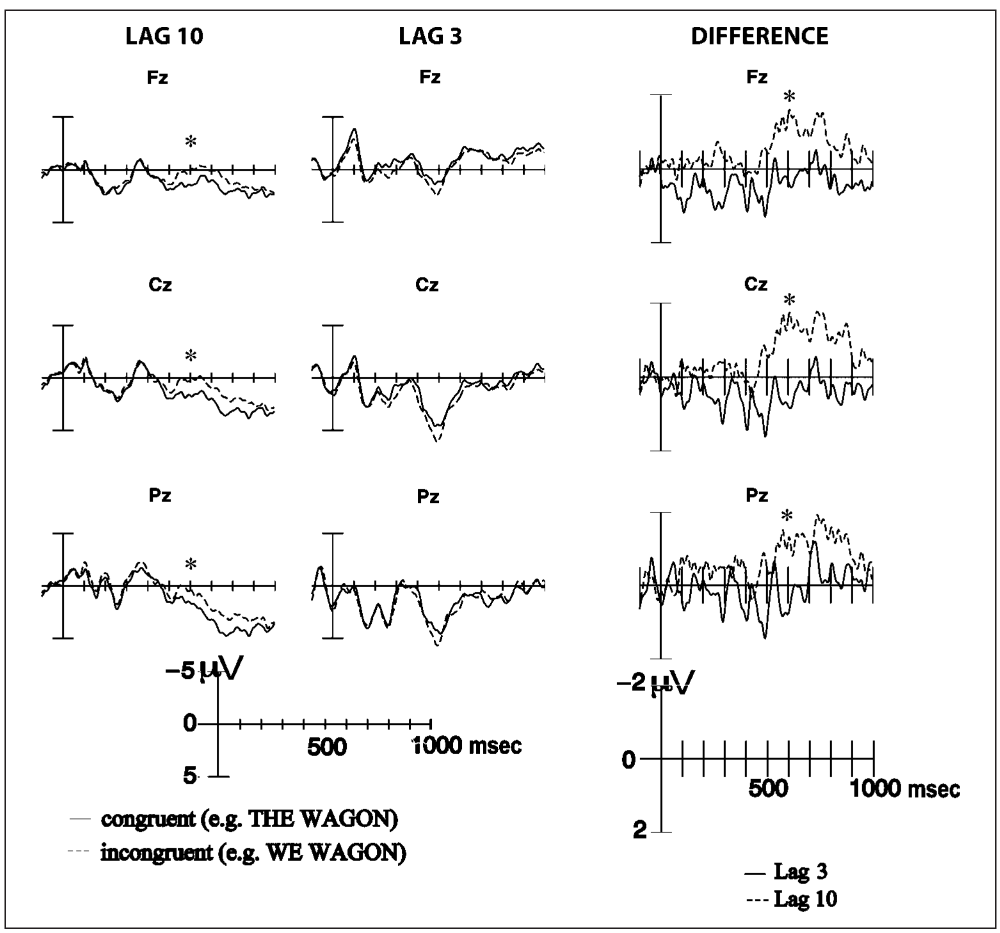

Figure 7. Grand-average ERP waveforms at midline sites to the second target (T2) in the syntactic block. Lag 10 targets are shown on the left, Lag 3 targets are shown in the middle, and difference waves, formed by subtracting related T2 trials from unrelated T2 trials, are shown on the right. The first two columns show congruent and incongruent trials, whereas the last column shows Lag 3 and Lag 10 trials. Note that the difference waveforms are plotted on a different scale than Lag 10 and Lag 3 averages.

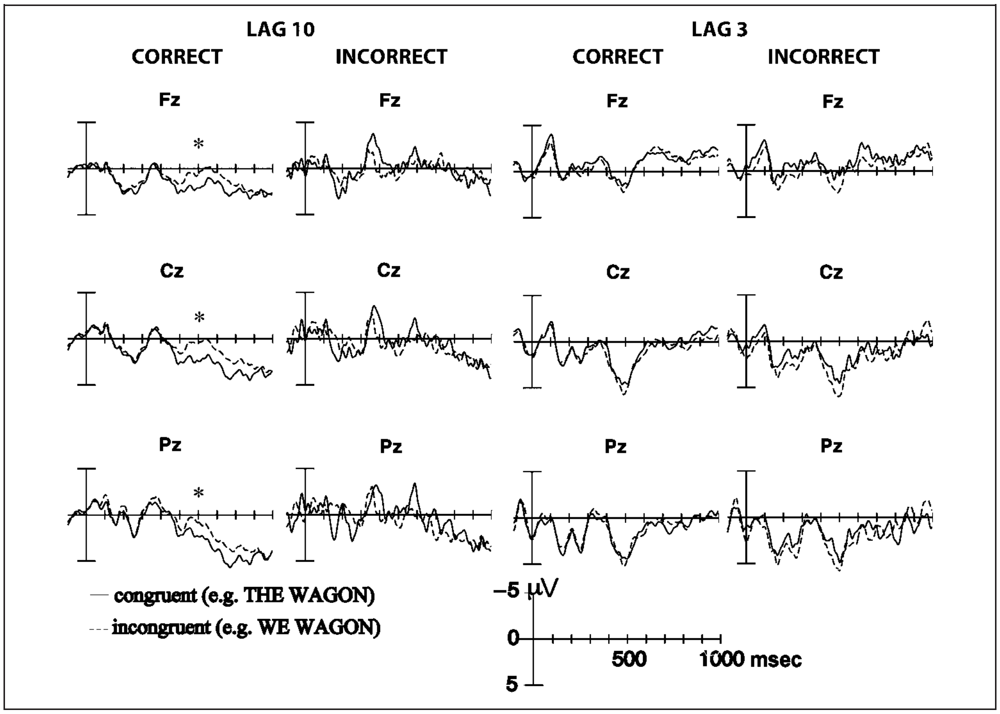

Figure 8. Grand-average ERP waveforms, showing ERPs to correctly reported and missed trials in the syntactic block for each lag condition, at midline sites.

sites. The difference in the congruency effect between correct and incorrect trials showed a different pattern at Lag 3 and Lag 10 that was greater over medial, posterior, and right hemisphere sites [Correctness × Congruency × Lag × Hemisphere × Anterior/Posterior × Laterality: $F(5, 100) = 2.81$, $p = .032$].

Follow-up analyses indicated that correct trials at Lag 10 showed a marginally significant congruency effect during the 500–700 msec time window [$F(1, 20) = 3.87$, $p = .063$; Figure 8], which was largest over medial sites [Congruency × Laterality: $F(1, 20) = 18.70$, $p < .001$]. This congruency effect was significant at medial sites [F3, FC5, C5, C3, P3, O1, F4, FC6, C6, C4, P4 and O2; $F(1, 20) = 5.37$, $p = .031$] and at midline sites [Fz, Cz, and Pz; $F(1, 20) = 7.69$, $p = .012$]. In contrast, incorrect Lag 10 trials showed no congruency effect [$F(1, 20) = 0.43$, $p = .519$]. Similarly, neither correct nor incorrect trials that occurred at Lag 3 showed a significant effect of congruency [correct: $F(1, 20) = 0$, $p = .99$; incorrect: $F(1, 20) = 1.54$, $p = .229$]. Thus, only correct Lag 10 targets elicited a reliable congruency effect.

This finding was confirmed in analyses of the difference waves, comparing the effect of lag within each correctness condition. As can be seen in the difference waves for the correct trials (Figure 9), Lag 10 targets elicited a larger congruency effect than Lag 3 targets [lag: $F(1, 20) = 4.34$, $p = .050$]. This lag effect was largest over medial sites [Lag × Laterality: $F(1, 20) = 4.66$, $p = .043$]. However, there was no significant effect of lag within the incorrect trials [$F(1, 20) = 0.414$, $p = .527$].

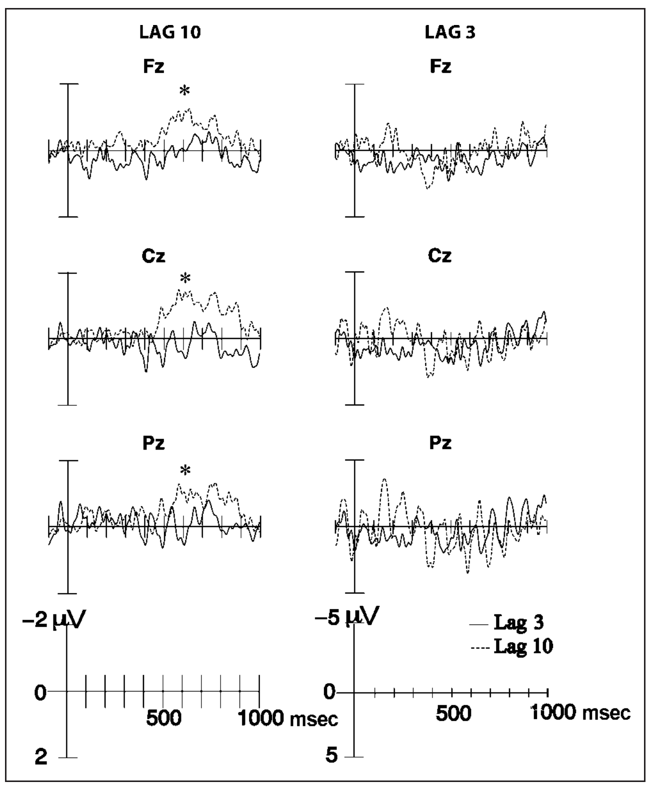

Figure 9. Difference waves, formed by subtracting related T2 trials from unrelated T2 trials in the syntactic block, for correctly reported and missed trials, by lag condition. Correctly reported trials are shown in the left column and missed trials are shown in the right column. Note that these averages are plotted on different scales.

ERP Results: Semantic and Syntactic Comparisons

Analyses of the congruency effects for the semantic and syntactic blocks, collapsed between correct and incorrect trials at Lag 10, were carried out to investigate possible differences in these effects. There was a main effect of type [$F(1, 20) = 13.77$, $p = .001$], reflecting the finding that the semantic N400 effect was larger overall than the syntactic congruency effect. After normalization of the data to account for amplitude differences, this analysis also revealed that the syntactic effect tended to show a distribution that was more anterior relative to the semantic effect [Type × Anterior/Posterior: $F(5, 100) = 2.58$, $p = .088$]. This can be seen in the topographical voltage maps of the semantic and syntactic effects (Figure 10).

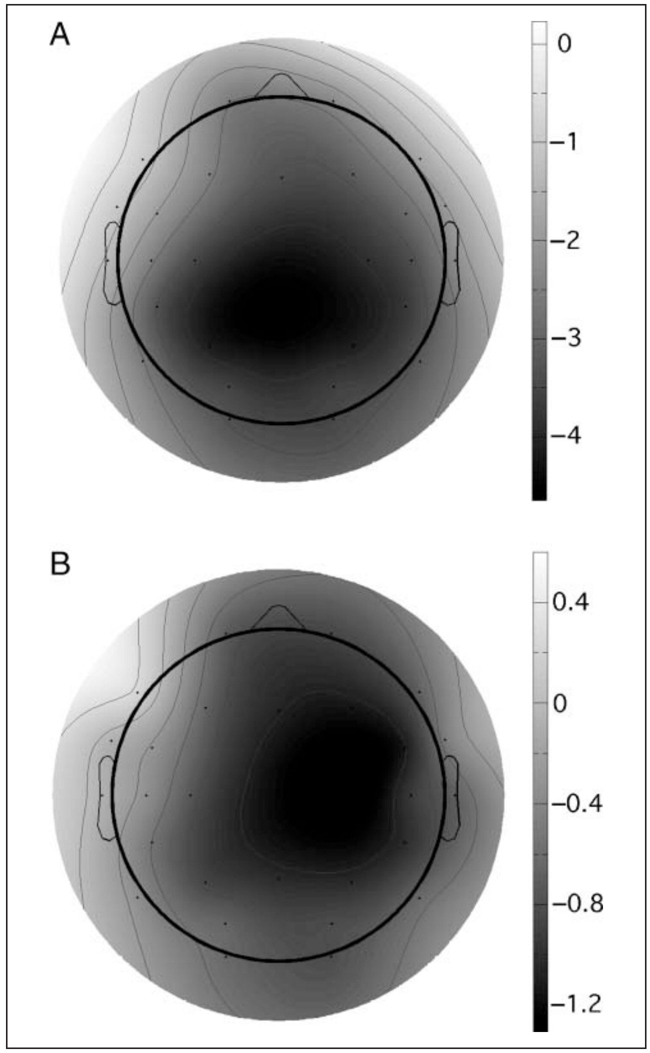

Figure 10. Voltage maps of the (A) semantic and (B) syntactic effects. Scales are relative to each effect.

DISCUSSION

Semantic Block

In the semantic block, participants were less accurate in reporting targets occurring during the AB period (Lag 3) compared to targets occurring outside the AB period (Lag 10). Correspondingly, the N400 component at Lag 3 was also reduced relative to the N400 at Lag 10. Much of this N400 reduction can be attributed to the higher proportion of missed targets that occurred at Lag 3: By separating missed targets from correctly reported targets, we showed that correct targets elicited a robust N400 effect. In contrast, incorrectly reported targets evoked no significant N400 effect.

These findings suggest that the N400 appears to reflect primarily a postlexical and controlled process, which is dependent upon the target word reaching conscious awareness. On trials where the target did not reach awareness and could not be correctly reported, no reliable N400 effect was elicited. At least in this paradigm, it appears that semantic identification and the N400 occur after the AB "bottleneck," the stage of processing where a loss of information is most likely to occur. Although previous research has shown that the N400 effect can be elicited by targets following masked primes, and thus, is sensitive to the buildup of automatically established contexts (e.g., Grossi, 2006; Kiefer, 2002; Deacon et al., 2000), this approach may not conclusively test whether the N400 elicited by targets is automatic (Holcomb et al., 2005). In addition, although one previous study has demonstrated a small N400 effect to unidentified target words (Stenberg et al., 2000), the conclusions drawn from this study are limited by the possibility that the targets with longer exposure durations may account for the effect. The present study demonstrates that the N400 effect is eliminated when participants are unaware of the identity of the target when exposure duration is held constant, providing novel evidence for the contention that the N400 is a direct index of controlled language processes.

One potential argument against this interpretation is the observation that, although the effect was not statistically significant, visual inspection of the incorrect Lag 3 waveforms suggested that blinked unrelated targets elicited some negativity relative to the related targets at posterior electrode sites, similar to a very weak N400 effect. This pattern in the data leaves open the possibility that automatic spreading activation, which can occur independently of awareness, may play a small and limited role in generating the N400. However, the lack of statistical significance reflects the fact that this effect was weak, and thus, may represent nothing but a chance occurrence. In addition, an examination of individual subject averages indicated that only a minority of subjects (9 of 21) showed any negativity in the 350 to 1000 msec poststimulus time window that could be construed as N400 activity, showing that this effect was not consistent from subject to subject. Thus, the N400 effect was much more robust, widespread, and reliable to correctly reported trials, lending more support to the idea that the N400 primarily reflects more controlled, conscious processes.

The finding of a reduced N400 effect to targets occurring during the AB period stands in contrast to results from two previous studies (Giesbrecht et al., 2007; Vogel et al., 1998). Both groups reported that, at least under conditions of low T1 load, no N400 suppression was observed during the AB period. One possible factor that may have contributed to the discrepancies between our findings and previous research is a difference in T1 perceptual load. Although the current paradigm was especially similar to that used by Vogel et al., it is difficult to exactly replicate complex parameters such as T1 load. In addition, unlike Vogel's and Giesbrecht's studies, the present study used a titration procedure to adjust the difficulty of the task to each individual subject, which may have contributed to an increase in T1 load overall. Confirming this idea, our behavioral results suggest that T1 in our study was more difficult to process and report (86% accuracy rate) than T1 in the earlier Vogel et al. study (93% accuracy rate) or in the Giesbrecht et al. low-load condition (98% accuracy rate). In addition, when we examined the effect of lag on averages including only correctly reported trials, we found that the N400 effect elicited by Lag 3 targets was smaller than the N400 elicited by Lag 10 targets. In other words, the N400 component was reduced during the AB period even for correctly reported targets. This is consistent with the results from Giesbrecht et al.'s study, who found that increasing T1 perceptual load can result in a suppression of the N400 effect during the AB period (Giesbrecht et al., 2007). Thus, it seems likely that a higher T1 load may at least partially account for our finding of a reduced N400 during the AB period, a result that contrasts with previous studies. Returning to Schneider and Schiffrin's two-process theory, as previously discussed, this finding provides further evidence that the N400 is mediated by controlled mechanisms that are limited in capacity, and thus, affected by concurrent T1 load.

One interesting and unexpected finding revealed by our analyses was a significant relatedness effect, opposite in polarity to the N400, elicited by incorrectly reported trials at Lag 10. This result suggests that the mechanism responsible for a miss that occurs outside the AB period is different from the attentional "bottleneck" that underlies the typical AB effect. Compared to a target occurring during the AB period, when competition for attentional resources is high and distractor interference is likely to prevent T2 from entering a more durable form of memory, a target that is displayed outside the AB period occurs after the subject has had adequate time to properly encode the first target and prepare for the second one. Based on the inverted N400 pattern, one possibility is that the prime is biasing the perception of the target. After the prime is presented, subjects may generate a set of likely targets based on the prime word. Because the presentation of the target word is brief (83 msec), subjects may incorrectly believe that one of these targets in the generated set appeared even if it actually did not, leading them to report an unrelated target as related. Similarly, if the target is related to the prime but does not happen to be included among the subject's generated set of expected words, the subject may erroneously believe that an unrelated target was flashed, also leading to an incorrect report. These types of errors would be expected to elicit the ERP pattern observed, in which related targets elicit more negative-going voltage activity than unrelated targets. One important caveat of this finding is that subjects missed relatively few trials outside the AB period, increasing variability and decreasing the signal-to-noise ratio of this average. Nonetheless, results are statistically robust and present an intriguing hypothesis for future investigation.

Syntactic Block

Behaviorally, in the syntactic block, we found that participants were significantly less accurate in reporting targets occurring within the AB period compared to targets occurring outside the AB period. At Lag 10, targets preceded by a grammatically incongruent context word elicited a late negativity that onset at approximately 500 msec. This syntactic incongruency effect showed a distribution that was more anterior relative to the semantic relatedness effect. At Lag 3, no significant effect of grammatical congruency was found.

This Lag 10 syntactic congruency effect is similar to previous studies (Hahne & Friederici, 1999; Frederici et al., 1993; Münte et al., 1993; high probability condition). Perhaps of most relevance is Münte et al.'s study, whose stimuli and task were most similar to those used in our paradigm. In that study, personal or possessive pronouns were followed by nouns or verbs, constituting either grammatically valid or grammatically invalid word pairs. Subjects were asked to decide whether each word pair constituted a syntactically correct phrase. The authors reported that ERPs elicited by targets preceded by grammatically incorrect primes yielded a negativity peaking between 500 and 550 msec poststimulus. Relative to the effect found in a semantic relatedness task that was also a part of the study, the syntactic congruency effect was later and had a more frontal distribution, similar to our findings. This syntactic congruency effect was reported to have a left frontal maximum, whereas the distribution of our effect was neither significantly left-lateralized nor anterior. Thus, these two effects, although similar, are not identical in distribution. However, the paradigm used in Münte et al.'s study and the paradigm used in our study vary on several parameters, including perceptual load, presence or absence of a concurrent task, presence or absence of distractor items, overall task difficulty, stimulus duration, stimulus onset asynchrony, and the specific word pairs used. Any number of these variables may have affected the distribution of the effect.

Neither the present experiment nor Münte et al.'s study found the hallmark biphasic response that is typically elicited in response to syntactic violations. This finding suggests that the minimal context provided by the prime word does not provide enough syntactic information to evoke the biphasic response. Given what previous research has revealed about the LAN and the P600, the absence of these components in response to impoverished syntactic content is not especially surprising. The LAN is thought to be an index of early first pass processes associated with syntactic processing, in which the assignment of initial syntactic structure is made on the basis of word category information (Friederici, 1995, 2002). In the case of word pairs, it is possible that there is insufficient structural information linking the prime word with the target word, and that even when these two words do not form a syntactically congruent phrase, this anomaly is not recognized as a word category violation and, therefore, not indexed by the LAN. Without a complete hierarchical syntactic structure provided by a full sentence, it may be that the more automatic processes reflected by the LAN are not triggered. In addition, although the presentation of full sentences, either auditory or visual, is a common occurrence in everyday life and represents a relatively ecologically valid stimulus set, the presentation of isolated pairs of words is much more artificial. It may be that the processing of word pairs is treated somewhat differently than normal language processing by the cognitive system, and thus, may be subserved by different, more controlled neural mechanisms. The absence of a P600 to isolated word pairs is also not unexpected. The P600 has been hypothesized to reflect structural reanalysis and repair processes, which may become necessary when an incoming word cannot be readily incorporated into semantic and verb argument information (Friederici, 1995). In other words, the P600 indexes an attempt to reanalyze and repair the initially built syntactic structure in order to rescue meaning. Previous research has shown that when meaning is reduced, as in semantically impoverished nonsense (Jabberwocky) sentences, the P600 is attenuated (Yamada and Neville, 2007; Canseco-Gonzalez, 2000; Münte, Matzke, & Johannes, 1997). In the case of word pairs, where little syntactic structure or semantic information is provided by the prime, the reanalysis and repair of syntactic structure to rescue meaning cannot take place, and no P600 is elicited.

This idea that complexity of linguistic content can have important effects on the elicited ERP response was addressed directly by Barber and Carreiras (2005). Spanish words pairs formed by an article and a noun were presented, in which gender or number agreement relationships were violated. In a second condition, agreement violations with the same word pairs were inserted in sentences. Violations occurring in a minimal context (word pair condition) evoked a broadly distributed negativity between 300 and 500 msec poststimulus, which was largest over frontal, central, and posterior sites, whereas violations that occurred in a rich linguistic context (full sentence condition) elicited both a LAN and a P600. Thus, these results support the proposal that the richness of syntactic context has an influence on the ERP response observed. Interestingly, the degree of sentential content does not have a similar effect on the N400, which is typically robust when either word pairs or sentences are presented, highlighting another difference between semantic and syntactic processing.

To address whether our late negative syntactic effect indexed a more automatic process or a controlled, awareness-dependent process, we isolated the correct and missed trials within the Lag 10 condition. We found that this effect was eliminated when subjects were not able to report the target. This result may indicate that, similar to the semantic relatedness effect, this effect is indexing a process that is controlled, and that is dependent upon conscious awareness. The relatively late latency of this effect, which onsets at approximately 500 msec, supports this interpretation, suggesting that this process is occurring well after the early time window when more automatic processes are thought to occur. Had this paradigm used a richer syntactic context, we might expect to see more evidence of automatic, awareness-independent syntactic processes, which would present an interesting follow-up experiment.

At Lag 3, we found no reliable effect of congruency, either in the overall average or in an average including only correctly reported targets. This finding suggests that this late congruency effect is vulnerable and dependent upon attentional resources. When competition for these resources is elevated, the effect is no longer observed, even when subjects successfully processed T2 and were able to correctly report the target. It may be that when perceptual and attentional load is high, neural resources are overwhelmed with the processing of T1 at the expense of late, controlled processing of the syntactic class of the word, as appears to be indexed by the late negativity effect. In other words, the lack of congruency effect at Lag 3 may be reflective of general impairments in processing associated with the perceptual and attentional demands that occur during the AB. This finding is consistent with at least one other study in the language processing AB literature, which found that the N400 was suppressed during the AB when perceptual or attentional load was high (Giesbrecht et al., 2007). It may be that T1 processing demands would not affect earlier, more automatic processes elicited by richer syntactic context.

Conclusion

In summary, our semantic results support the argument that the N400 is an index of a controlled, postlexical process. By directly comparing the ERP response elicited by reported and missed trials, the current study employs a powerful paradigm with which to investigate the effect of awareness on a given ERP effect. The question of whether the N400 reflects a controlled or automatic process represents an important and enduring debate in this field, and these data contribute to our understanding of the functional significance of this component. Our syntactic results provide further corroboration for the finding that the processing of grammatical violations in a minimal sentential context is indexed by a late negativity. This late negative response appears to reflect a controlled process dependent upon conscious awareness.

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