Word Semantics Is Processed Even without Attentional Effort

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Abstract

■ We examined the attentional modulation of semantic priming and the N400 effect for spoken words. The aim was to find out how the semantics of spoken language is processed when attention is directed to another modality (passive task), to the phonetics of spoken words (phonological task), or to the semantics of spoken words (word task). Equally strong behavioral priming effects were obtained in the phonological and the word tasks. A significant N400 effect was found in all tasks. The effect was stronger in the word and the phonological tasks than in the passive task, but there was no difference in the magnitude of the effect between the phonological and the word tasks. The latency of the N400 effect did not differ between the tasks. Although the N400 effect had a centroparietal maximum in the phonological and the word tasks, it was largest at the parietal recording sites in the passive task. The effect was more pronounced at the left than right recording sites in the phonological task, but there was no laterality effect in the other tasks. The N400 effect in the passive task indicates that semantic priming occurs even when spoken words are not actively attended. However, stronger N400 effect in the phonological and the word tasks than in the passive task suggests that controlled processes modulate the N400 effect. The finding that there were no differences in the N400 effect between the phonological and the word tasks indicates that the semantics of attended spoken words is processed regardless of whether semantic processing is relevant for task performance. ■

INTRODUCTION

Target words that are preceded by semantically related prime words are recognized faster and more accurately than targets preceded by unrelated words (Meyer & Schvaneveldt, 1971). This process, semantic priming, provides a way to study the functional organization of semantic memory (Kutas & Hillyard, 1989; Meyer & Schvaneveldt, 1971) and language systems (Henson, 2003). With ERPs, semantic priming can also be investigated without overt behavior: The N400 ERP is smaller to a target word when it is preceded by a semantically related than unrelated word (e.g., Kutas & Hillyard, 1980). This is called the N400 effect. Similarly, in fMRI studies, behavioral priming is associated with reduced activity in several cortical regions (e.g., Schacter, Wig, & Stevens, 2007; Henson, 2003). The effect can be observed either by comparing semantically congruent and incongruent terminal words of sentences (e.g., the stars are shining in the *sky* vs. the stars are shining in the *house*; Kutas & Hillyard, 1980) or semantically congruent and incongruent word pairs (e.g., *east-west* vs. *dog-west*; Bentin, McCarthy, & Wood, 1985). Perhaps the most commonly used paradigm to study semantic priming is the lexical decision task, in which subjects are asked to judge whether the target word is a word or a nonword.

The N400 effect is typically strongest at centroparietal recording sites (Kutas & Hillyard, 1980). The effect is usually more pronounced in the right than left recording sites for written words but symmetrical for auditorily presented words (Van Petten & Luka, 2006). Neuroimaging studies have shown that activity in the middle (e.g., Gold et al., 2006; Rossell, Price, & Nobre, 2003; Mummery, Shallice, & Price, 1999) and superior temporal gyrus/sulcus (e.g., Rissman, Eliassen, & Blumstein, 2003; Rossell et al., 2003; Mummery et al., 1999) is associated with semantic priming. In some of the studies, also the inferior or the middle frontal gyrus were shown to be activated during semantic priming tasks (Gold et al., 2006; Rissman et al., 2003; Rossell et al., 2003; Kotz, Cappa, von Cramon, & Friederici, 2002; Mummery et al., 1999). These two neuronal substrates may, however, have a different role in semantic priming. The temporal areas were suggested to be involved in lexical-semantic processing in contrast to the prefrontal cortex, which was proposed to be recruited by attentional or selection processes.

Two kinds of processes have been proposed to contribute to semantic priming: automatic (Collins & Loftus, 1975) and strategic/attentional (Posner & Snyder, 1975). According to Neely and Keefe (1989) and Neely, Keefe, and Ross (1989), at least one automatic and two controlled processes contribute to semantic priming. First, the

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spreading activation theory postulates that activation automatically spreads from one activated representation of a word to another in a semantic network (Collins & Loftus, 1975). The second mechanism, expectancy-induced priming, is a controlled process in which the semantic meaning of an activated word representation is used to generate an expectancy set for related words (Becker, 1976). It has, however, been proposed that expectancy-induced priming is only evoked in certain task types, not in natural language processing (Brown, Hagoort, & Chwilla, 2000). The third process, semantic matching, is a controlled process in which the semantic similarities of words are evaluated in the postlexical phase (Neely, 1977). The amplitude of the N400 component for a semantically related target word is suggested to be reduced when the prime word is activated because less activation is needed to recognize the word (Holcomb & Neville, 1990) or because lesser inhibition of irrelevant information is needed (Debruille, 2007).

Attention has a substantial role in language processing in an increasingly complex stimulus environment. Attentional modulation of semantic processing has been widely studied with semantic priming and the N400 effect. Several studies have investigated the N400 effect in experimental paradigms in which subjects were instructed to attend other than semantic features of visually presented word pairs. As indexed by the Stroop effect, it is slower to name colors of incongruent words (e.g., word ''blue'' written with red color) than those of colored squares, suggesting that letter strings are read even when the task does not require it (McLeod, 1991). However, results on the automaticity of semantic processing of written words have not been entirely consistent. In most studies in which subjects were asked to judge whether a target letter was present in the prime word and to make a lexical decision of the target word, the N400 effect was found (Dombrowski & Heil, 2006; Heil, Rolke, & Pecchinenda, 2004; cf. Marí-Beffa, Valdés, Cullen, Catena, & Houghton, 2005). The effect was also present in a study in which the task was to decide whether a target letter was present in the word pair (Kutas & Hillyard, 1989). However, significant N400 effect was not found when subjects attended the size of letters (Chwilla, Brown, & Hagoort, 1995; Deacon, Breton, Ritter, & Vaughan, 1991) or the vowel-consonant pattern of the first and last letters between written words (Besson, Boaz, Fischler, & Raney, 1992). The effects of attention on the visual N400 effect have also been studied in paradigms in which the subjects were instructed to selectively attend only particular stimuli. In one study, the effect was only found when the word pairs were presented to the attended visual field (McCarthy & Nombre, 1993). In a study in which attention was directed to words written in a particular color, the N400 effect was found when only the prime words were attended, but not when only target words or neither primes nor targets were attended (Kellenbach & Michie, 1996).

In everyday life, attention plays an important role in the perception of spoken language, for instance during discussions with multiple speakers and when speech attracts attention while paying attention to something else. Several auditory studies have investigated the role of attention on the N400 effect. The N400 effect was found when subjects were asked to decide whether the prime and the target words rhymed with each other, but it was weaker than when subjects made semantic judgments about the words (Perrin & García-Larrea, 2003). In studies that used sentences instead of word pairs as stimuli, the effect was found when the subjects decided whether a certain phoneme or letter was present in the sentence (Connolly, Stewart, & Phillips, 1990) or whether the intonation contour of the sentence was congruous or not (Astésano, Besson, & Alter, 2004). In a study by Hohlfeld and Sommer (2005), the N400 effect was present when subjects attended the pitch of the target word, but according to the authors, the effect was weaker than in tasks that require semantic processing. Moreover, during the second experiment, the subjects did a visual task at the same time with the pitch discrimination task, and as processing load increased, the N400 effect diminished. Furthermore, the N400 effect was not found when subjects were instructed to count nonwords among word pairs (Bentin, Kutas, & Hillyard, 1993). To our knowledge, there is only one auditory study comparing the N400 effect during tasks that require ignoring and attending the words. This study used a dichotic listening paradigm, and the results showed that the N400 effect was found only for words that were presented to the attended channel (Bentin, Kutas, & Hillyard, 1995). The N400 effect has, however, been found for spoken words presented during some sleep stages (Ibáñez, López, & Cornejo, 2006; Perrin, Bastuji, & García-Larrea, 2002; Brualla, Romero, Serrano, & Valdizán, 1998).

Prior visual and auditory investigations have brought both positive and negative results on whether the N400 semantic priming effect occurs when the semantics of words is not attended, and only few studies have investigated the N400 effect for ignored words. The effects of attentional modulation on the scalp distribution of the N400 effect have not been addressed in the previous studies due to relatively small number of electrodes. The present study aimed at investigating in a greater detail how the direction of attention modulates semantic priming of spoken words. Attentional effects on the amplitude, latency, and scalp distribution of the N400 effect as well as on behavioral semantic priming were investigated when attention was directed to the semantic properties of the words, to other than semantic information of the words, and away from the words. The explicit semantic and phonological tasks asking the subjects to make overt decisions about the word pairs were used to augment processes related to attention, effort, and strategic processes. The passive task, in which the subjects were asked to perform a visual task and ignore the spoken words, was used to compare controlled semantic processing with implicit semantic processing outside the focus of effortful attention.

METHODS

Subjects

Twenty volunteers aged between 20 and 32 years (mean = 26 years) participated in the study. The subjects were right-handed, native Finnish speakers, had normal or corrected-to-normal vision, and reported no history of neurological or hearing disorders. They gave written informed consent and were paid for participation. The study was accepted by the ethical committee of the Department of Psychology, University of Helsinki. Before the experiments, subjects were divided in two groups of 10 subjects (7 women in each group) that performed the task conditions in different order. The mean ages of the subject groups did not differ from each other ($t(18) = -0.07$, $p < .96$).

Stimuli

The stimuli were two-syllable Finnish spoken nouns that were arranged into 178 prime-target pairs (Appendix A). Half of the pairs consisted of semantically related words and half of them of semantically unrelated words. The prime and the target words were identical in the related and the unrelated word pairs; for example, the word ''west'' served as a target word in one related (*east-west*) and one unrelated (*dog-west*) word pair. All words were two-syllable nouns. The prime words consisted of three to seven letters and the target words of five letters. The durations of the prime and target words varied between 403 and 989 msec (mean duration = 698 msec, *SD* = 119 msec) and 551 and 944 msec (mean duration = 709 msec, *SD* = 78 msec), respectively. In both related and unrelated word pairs, the probability of the words in one pair ending with the same letter (e.g., *koira-kissa*) was 0.20. The words were recorded using a DAT tape recorder (sampling rate 44.1 kHz) and edited with Cool Edit 2000 (Syntrillium Software Corp., Phoenix, AZ) program. The speaker was a native Finnish female.

The stimuli used in the study were chosen based on two pretests. In the first pretest, 24 subjects (16 women) aged between 20 and 62 years (mean age = 28 years) rated the semantic relationship of 110 semantically related and 110 unrelated written word pairs. The semantically related and unrelated word pairs were presented in a stochastic order that differed between subjects. The subjects were asked to rate each word pair using a scale from 1 (*no semantic relation*) to 5 (*high semantic relation*). The semantically related and unrelated word pairs that were, on average, rated 4 or more and 2 or less, respectively, were chosen for the second pretest. Because some of the pairs were removed, the unrelated word pairs were revised to achieve identical prime and target words in the related and the unrelated word pairs. The resulting 100 related and 100 unrelated word pairs were recorded as described earlier, and the second pretest was conducted. In the second pretest, nine volunteers (six women) aged between 21 and 28 years (mean age = 23 years) were asked to listen to the word pairs via headphones and indicated with a button press whether the word pairs were semantically related or unrelated. The word pairs that were rated differently than in the first pretest at least by two subjects or that had a mean RT of more than 1200 msec (mean RT for all words pairs = 1050 msec, *SD* = 261 msec) were excluded. The unrelated word pairs were again revised to achieve identical prime and target words in the related and the unrelated word pairs.

Procedure

The experiment consisted of three task conditions. In each task, the word pairs were identical but the order of the word pairs was different. The SOA was 1100 msec between the onsets of the prime and the target words in each word pair and 3000 msec between the onsets of a target word and the consecutive prime word (Figure 1). The words were presented via headphones. The hearing threshold of each subject was measured before the recordings, and the volume of the stimuli was set to 50 dB above the threshold. In case the subject requested, volume was increased. Subjects were seated in a chair in front of a computer screen in an electrically shielded room. They were instructed to avoid blinking and moving during the experiment. Each task condition lasted for 12 min, and the subjects were allowed to have a break between the tasks. Instructions concerning the task conditions were given just prior each task.

In the *passive task* condition, subjects watched a silent nature film subtitled in Finnish. They were instructed to

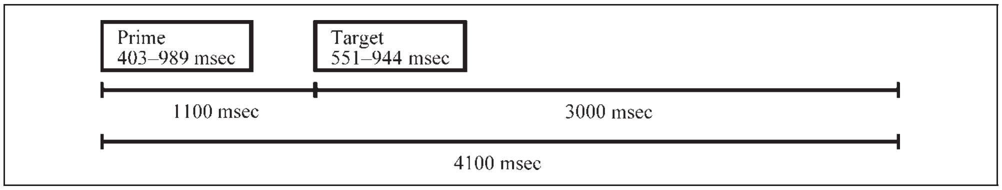

Figure 1. Stimulus onset asynchronies during one trial.

ignore the word pairs presented through headphones and were asked to learn the details of the film in anticipation of a subsequent test. After the task, the subjects were asked to fill in a written questionnaire regarding the content of the film. The questionnaire consisted of nine questions about the events of the film and the facts given in the subtitles. Each question had three response alternatives.

In the *phonological task*, subjects were asked to indicate with a button press whether the two words in a word pair ended in the same letter (20% of both semantically related and unrelated word pairs). It should be noted that all letters, including the final letter of a word, are pronounced in Finnish language, which is transparent, that is, there is a direct correspondence between the written and the spoken letters. During the *word task*, subjects were asked to indicate with a button press whether the words in each word pair were semantically related or unrelated. Before the phonological and the word tasks, the subjects practiced the tasks with 10 word pairs different from those used in the experiment. They were asked to respond as fast and accurately as possible. To avoid eye movements, subjects were instructed to look into the bottom of the screen. In both tasks, half of the subjects in both groups responded with the right index finger to words ending with the same letter or to semantically related words, and with the middle finger to words ending with different letters or to semantically unrelated words. The order of the response fingers was reversed for the rest of the subjects.

Both subject groups performed the passive task first but the two other tasks in a different order. The first group performed the phonological task before the word task, and the second group performed the word task before the phonological task. Both groups performed the passive task first to ensure that the subjects would not be aware of the importance of the auditory stimuli during the passive condition. For this reason, the subjects were also given instructions concerning each task just prior to the task.

EEG Recording and Analysis

An electrocap (see Virtanen, Rinne, Ilmoniemi, & Näätänen, 1996) was used to record continuous EEG from 58 Ag/AgCl electrodes referenced to the nose. Some electrode placements approximately matched the 10–20 system (Jasper, 1958; Figure 2). Additional electrodes were placed on the right and the left mastoids. Horizontal and vertical eye movements were monitored with electrodes attached lateral to both eyes and above and below the left eye. Impedances were kept under 15 kΩ. The EEG was amplified with NeuroScan SynAmps (bandpass = 0.1–40 Hz, sampling rate = 1000 Hz).

EEG epochs (1200 msec, beginning 200 msec before target onset) were averaged separately for each subject, task, and type of target word. Epochs including artifacts exceeding ±100 μV in any channel were excluded from the averages. Frequencies exceeding 30 Hz were digitally filtered (24 dB/octave), and the average waveforms were baseline corrected. The epochs were grand averaged for each task and relatedness condition. Difference waveforms were formed for each subject and grand average by subtracting the ERP to the related target waveform from that to the unrelated target waveform.

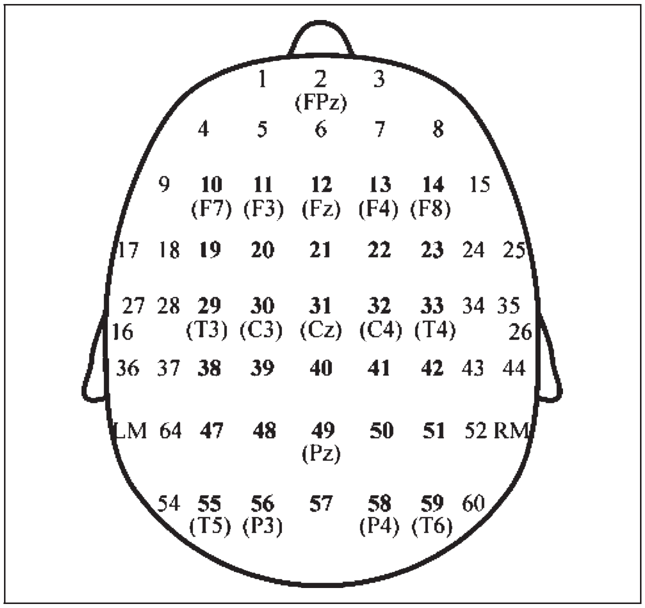

Figure 2. Electrode locations and approximate equivalencies with the 10–20 system. LM = left mastoid, RM = right mastoid.

Statistical Methods

The behavioral results (RTs and the proportions of incorrect and missing responses) were subjected to a two-way (Task × Relatedness) repeated measures ANOVA. The peak latencies of the grand-averaged difference waveforms in each task were measured from the channel with the highest peak amplitude. Three 100-msec latency windows, the second of which centered at the peak latency of the difference wave in each task, were included in the analyses. The mean amplitudes of the N400 effect were measured across the latency windows from each subject's difference waveforms in each task and channel. To test the significance of the N400 effect, we compared the mean amplitudes with a baseline of 0 μV with a two-tailed one-sample *t* test separately for each task and latency window.

Thirty electrodes were included in the ANOVAs. Only the mean amplitudes from the second latency window were used. The effect of subject group (subjects performing first the word and then the phonological task and subjects having a reversed order of the tasks) was tested with a four-way (Subject group × Task × Anterior–posterior distribution × Laterality) repeated measures

Table 1. RTs, *SEMs*, and Percentages of Missing Answers (Mis) and Incorrect Answers (In) in the Letter and the Word Tasks

	Semantically Related				*Semantically Unrelated*			
Condition	*RT (msec)*	*SEM (msec)*	*Mis (%)*	*In (%)*	*RT (msec)*	*SEM (msec)*	*Mis (%)*	*In (%)*
Letter task	1126	39	0.34	0.62	1171	38	0.22	0.81
Word task	1008	42	0.06	2.19	1066	40	0.06	0.62

ANOVA. Because the main effect of subject group, $F(1, 18) = 0.65$, $p < .44$, and the interaction between the subject group and task, $F(2, 36) = 0.723$, $p < .5$, were not statistically significant, the group variable was excluded from further analyses. The distribution of the N400 effect and the differences between tasks were then tested with a three-way (Task × Anterior–posterior distribution × Laterality) repeated measures ANOVA. The sources of interesting significant effects (Task, Task × Laterality, Task × Anterior–posterior distribution) were tested with the least significant difference post hoc test.

To study the latency differences of the N400 effect between tasks, we determined the individual peak latencies from a 200-msec latency window (425–625 msec), which included most of the single subject peak amplitudes. Latencies were tested with a three-way (Task × Anterior–posterior distribution × Laterality) repeated measures ANOVA that included 30 electrodes. All amplitude and latency results of the ANOVAs were Greenhouse–Geisser corrected for nonsphericity when appropriate.

RESULTS

Behavioral Data

Immediately after the passive task, the subjects were asked to fill in a questionnaire testing how well they had learned the contents of the film. The performance in this multiple-choice test was very accurate (mean = 93% correct responses, *SD* = 13%). RTs and percentages of missing and incorrect responses in the phonological and the word tasks are given in Table 1. There was a significant difference in the mean RTs between the two tasks, $F(1, 19) = 18.40$, $p < .001$, probably because listening to the final letters of the word stimuli was required in the phonological task. A semantic priming effect was observed between the mean RTs of the related and unrelated target words, $F(1, 19) = 29.87$, $p < .001$ (Figure 3). However, the interaction between the task and the type of target word (related or unrelated) was not significant, $F(1, 19) = 0.79$, $p < .4$, indicating that semantic priming effect was equally strong in both phonological and word tasks. The number of incorrect responses was not significantly different between related and unrelated words, $F(1, 19) = 1.61$, $p < .3$, nor between the two task conditions, $F(1, 19) = 1.04$, $p < .4$. The number of missed responses differed neither according to the type of target word, $F(1, 19) = 0.32$, $p < .6$, or task, $F(1, 19) = 3.62$, $p < .08$.

ERP Data

The average percentage of accepted EEG epochs was 64% (*SD* = 14%) in the passive video task, 75% (*SD* = 16%) in the phonological task, and 79% (*SD* = 17%) in the word task. The N400 effect was statistically significant in all three task conditions (Figure 4, Table 2). The ANOVA results showed, however, that the influence of task on the N400 effect amplitude was significant, $F(2, 38) = 5.18$, $p < .05$. According to post hoc tests, the magnitude of the N400 effect was smaller in the passive task than in the phonological ($p < .01$) and the word tasks ($p < .05$), but there was no significant difference between the phonological and the word tasks ($p < .85$).

The distribution of the N400 effect is shown in Figure 5. The main effects of anterior–posterior axis, $F(5, 95) = 13.30$, $p < .001$, and laterality, $F(4, 76) = 11.62$, $p < .001$, of the N400 effect were significant, and

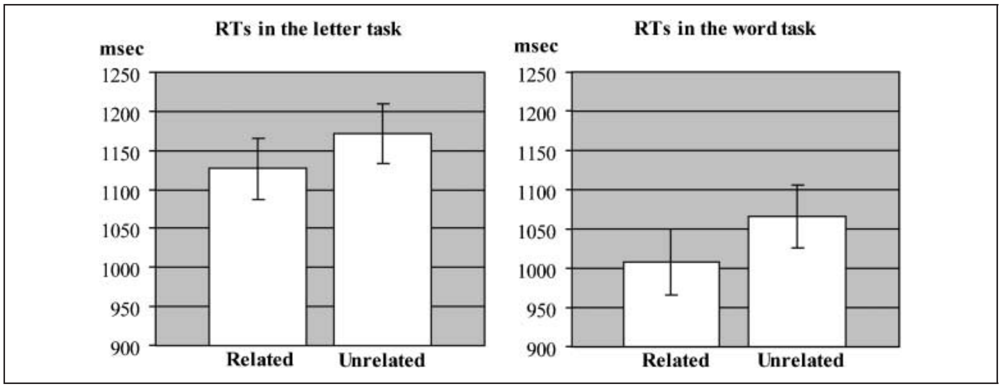

Figure 3. The average RTs (columns) and *SEMs* (error bars) of the phonological and the word task correct responses.

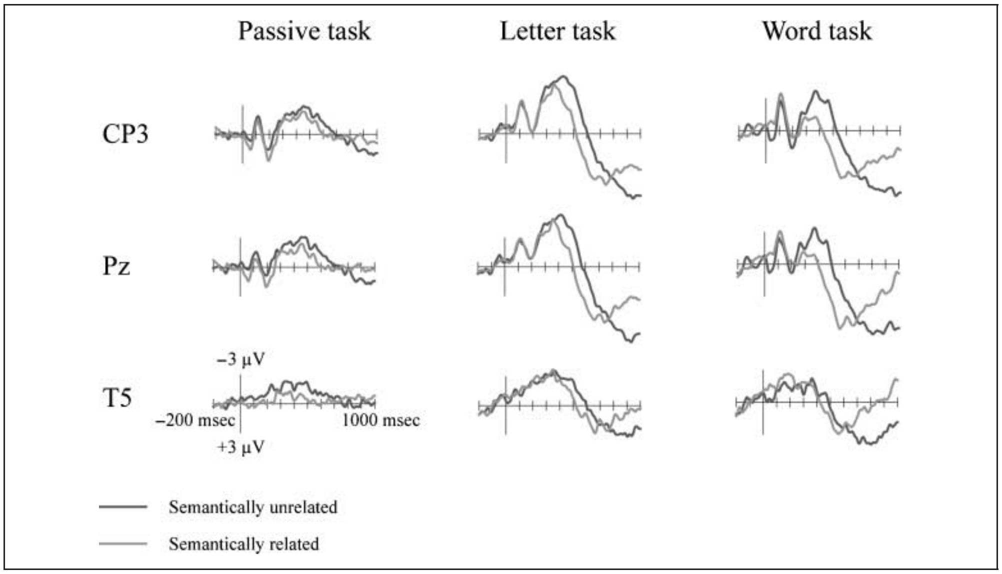

Figure 4. Average ERPs for semantically unrelated and related target words in the passive, phonological, and word tasks at the electrodes with the highest peak amplitudes: electrode near T5 in the passive task, electrode CP3 (between C3 and Pz) in the phonological task, and electrode near Pz in the word task.

there were also significant interactions between task and anterior–posterior axis, $F(10, 190) = 4.67$, $p < .001$, and between task and laterality, $F(8, 152) = 5.40$, $p < .001$. According to post hoc tests, the N400 effect in the passive task was more pronounced at the posterior than central or frontal recording sites (all p values <.04). In the phonological and the word tasks, the effect was stronger at the central than at the frontal or parietal recording sites (all p values <.001). Post hoc tests about laterality revealed that in the phonological task, the N400 effect was stronger at the middle and left recording sites than at the right recording sites (all p values <.01). In the word task, the effect was stronger at the middle than the lateral sites (all p values <.01), and there was no difference between the left and the right sides ($p < .09$). The N400 effect was stronger in the left side during the phonological task than the word task (all p values <.05). There were no significant differences between the middle and the lateral sites in the passive task (all p values >.13).

The effects of task, $F(2, 38) = 1.49$, $p < .24$, anterior–posterior distribution, $F(5, 95) = 0.63$, $p < .68$, or laterality, $F(4, 76) = 0.68$, $p < .61$, on the latencies of the N400 effect and the interactions between them (all p values >.38) were not significant.

DISCUSSION

The present study investigated the effects of attentional modulation on semantic priming by recording the N400

Table 2. Peak Latencies, Mean Amplitudes, *SEM*s, *t* Values, and Significance Levels of the N400 Effect during Different Task Conditions and Time Windows Measured from the Difference Waves Relative to a 0-µV Baseline

Condition	*Electrode*	*Peak Latency (msec)*	*Time Window (msec)*	*Mean (µV)*	*SEM (µV)*	*t(19)*	*p*
Passive task	55	489	339–439	−1.21	0.34	−3.53	**
			439–539	−1.31	0.45	−2.90	**
			539–639	−1.02	0.43	−2.40	*
Letter task	39	528	378–478	−2.26	0.52	−4.35	***
			478–578	−3.71	0.53	−7.02	****
			578–678	−3.05	0.62	−4.91	****
Word task	49	463	313–413	−2.14	0.52	−4.12	***
			413–513	−3.67	0.67	−5.49	****
			513–613	−3.15	0.67	−4.72	***

*$p < .05$.

**$p < .01$.

***$p < .001$.

****$p < .0001$.

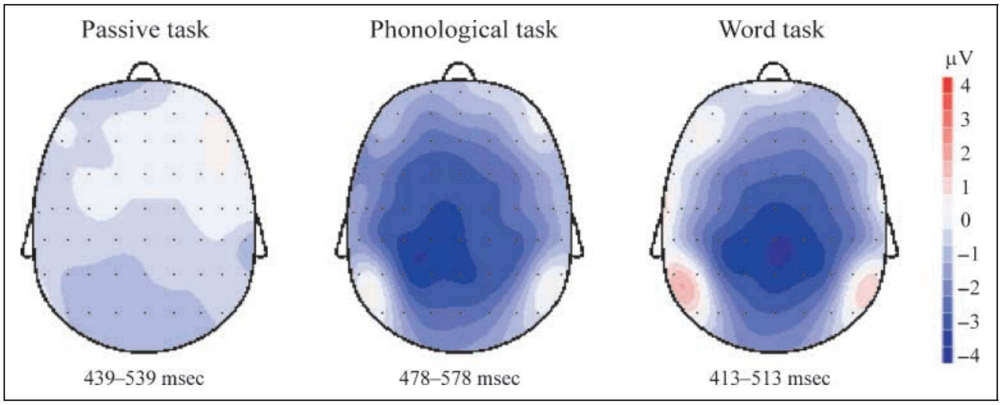

Figure 5. Scalp distribution of the N400 effect (average amplitude measured from difference waves) during the middle time window of each task condition.

effect for spoken words. Semantic priming was observed in both behavioral data (shorter RTs for semantically related than unrelated word pairs) and ERPs during the word task, in which subjects were asked to attend the semantic features of the word stimuli, and during the phonological task, when subjects were to attend phonetic features of the stimuli. Furthermore, the magnitude of behavioral and N400 semantic priming effect did not differ between the two tasks. During the passive task, when subjects were asked to attend visual information instead of the spoken words, the N400 effect was also obtained, although its magnitude was smaller than during the conditions in which the task was to attend to the word pairs. Differences between tasks were also found in the spatial distribution of the N400 effect; however, the latency of the effect was similar in all task conditions.

The present findings indicate that the N400 effect for spoken words is obtained even when attention is directed to another modality, suggesting that semantic processing of speech occurs without effortfully attending to speech. High accuracy in the multiple-choice test measuring how well the subjects had learned the details of the film in the passive condition indicates that the subjects attended the film. The N400 effect in the passive task of the present study could also result from unintended slipping of attention to the auditory stimuli during the visual task. However, activity related to semantic priming for spoken words was also found in a fMRI study when the subjects were engaged in a demanding visual task (Rämä, Relander, Carlson, Salonen, & Kujala, 2006). Furthermore, the N400 effect has been found during some sleep stages (Ibáñez et al., 2006; Perrin et al., 2002; Brualla et al., 1998). Our results bring further support for semantic priming outside the focus of attention during more natural daily listening conditions.

To our knowledge, this study is the first to show the N400 effect for spoken words during a task that requires focusing attention away from the words. In a dichotic listening study by Bentin et al. (1995), in which the subjects were asked to listen only to words presented to one auditory channel, an N400 effect for unattended words was not found. Earlier it was shown by recording the mismatch negativity response that processing of unattended auditory stimuli is more difficult during dichotic listening than when attention is directed to another modality (Näätänen, Paavilainen, Tiitinen, Jiang, & Alho, 1993). Consequently, the discrepancy of the results between the present study and the study of Bentin et al. (1995) may be explained by differences in cognitive requirements of the primary tasks in these two studies. It is possible that simultaneous semantic processing of spoken verbal stimuli in the study by Bentin et al. loaded processing capacity too much to enable simultaneous processing of unattended speech. In contrast, when attention is actively focused to another modality, as in the present study and the fMRI study by Rämä et al. (2006), or when there are no competing stimuli, as in the above mentioned sleep studies (Ibáñez et al., 2006; Perrin et al., 2002; Brualla et al., 1998), simultaneous semantic processing of speech seems to be possible.

Results from the present study show, however, that the N400 effect was smaller in the passive task compared with the phonological and word tasks. It could be argued that the differences in results between tasks are related to motor functioning rather than to attentional demands of the tasks because in the passive condition, contrary to the other conditions, subjects were not required to make a binary decision and a motor response time locked to the target word. However, making subtraction waveforms for the responses elicited by the unrelated and the related word pairs presumably removes most of the effects of decision making and motor response from the waveforms. Hence, it is plausible that also controlled processes contribute to the N400 semantic priming effect, as reflected by the difference in the size of the effect between passive and other conditions.

Semantic priming effect was obtained both behaviorally and electrophysiologically during the phonological and word tasks. The magnitude of the behavioral semantic priming and the N400 effect did not differ between these conditions. These findings suggest that attending word features that are irrelevant in semantic processing does not reduce the magnitude of semantic priming. This interpretation was supported by the fact that the performance order of the phonological and word task conditions did not affect the magnitude of the N400 effect. The N400 effect in the phonological task could have increased in the subject group that performed the word task before the phonological task, if performing the semantic word task would have encouraged them to pay attention to the semantic properties of the stimuli also during the phonological task. Likewise, the N400 effect could have decreased in the word task in the group that did the word task last due to fatigue and repetition. However, the N400 effects seem not to depend on these factors because the magnitude of the N400 effect did not differ between groups that performed the tasks in different order. Because repetition effects were not wound between the word and the phonological tasks, it is neither plausible that there are repetition effects to the word and the phonological tasks from the passive task, which was introduced first to all subjects to ensure that the subjects did not realize the importance of the auditory stimuli during the passive task (i.e., to avoid carry-over effects of attention).

In the present study, the N400 effect was most pronounced over the centroparietal cortex during the phonological and the word tasks but seems weaker below the mastoids, which may point to generators in the temporal cortices like in the study of Johnson and Hamn (2000). The temporal cortex has also been suggested to contribute to the N400 effect in intracranial ERP studies (McCarthy, Nombre, Bentin, & Spencer, 1995; Nombre & McCarthy, 1995). On the other hand, it has been suggested that a large cortical area involving possibly several generators contributes to the N400 effect (Van Petten & Luka, 2006). Accordingly, the scalp distribution in the present study differs between task conditions with different attentional demands. During the phonological and the word tasks, the N400 effect was strongest at the centroparietal recording sites, whereas during the passive task, it was strongest at posterior recording sites. In addition to the temporal lobes, several fMRI studies have also found inferior frontal cortex activity for semantic priming, generally considered as reflecting strategic processing (for a review, see Van Petten & Luka, 2006). It is plausible that lesser prefrontal activity during unattended semantic processing explains the more posterior distribution of the N400 effect in the passive task compared with the phonological and the word tasks in the present study.

In addition, also the lateralization of the N400 effect varied between task conditions. Generally, phonological, lexical, and syntactic processing recruits the left hemisphere more than the right one, but it seems that semantic processing involves both hemispheres with variable degrees of laterality (Pulvermüller, 2007). Accordingly, in earlier auditory studies, significant lateralization of the N400 effect has usually not been found (Van Petten & Luka, 2006), but significant lateralization results both to the left (e.g., Hahne & Friederici, 2002; Holcomb & Neville, 1990) and to the right (e.g., Astésano et al., 2004; van den Brink, Brown, & Hagoort, 2001) however exist. Lateralization results from fMRI studies have also been discrepant: Temporal activation found for semantic priming has in some cases been bilateral (Rämä et al., 2006; Friederici, Rüschemeyer, Hahne, & Fiebach, 2003; Rissman et al., 2003; Ni et al., 2000), sometimes only found in the left side (Kotz et al., 2002) or, during passive semantic priming, only in the right side (Rämä et al., 2006). In the present study, the N400 effect was more pronounced at the left than the right recording sites during the phonological task but not during the word and passive tasks. Further, it seems that during the phonological task, semantic processing in the left hemisphere is increased compared with both the right hemisphere in the phonological task and with the left hemisphere in the word task. Evidently, at this stage, only speculations about the discrepant results between the task conditions in the present study and between earlier studies can be presented. Perhaps clear lateralization cannot be found because of, firstly, the networks underlying semantics are widespread, involving both hemispheres (Pulvermüller, 2007) and, secondly, due to the poor spatial resolution of ERPs. Also, although the subtraction method presumably removes the effects of phonological processing in the phonological task, it can be speculated that phonological processing, which is known to be left lateralized, somehow increases also semantic processing in the left hemisphere, perhaps to ease phonological processing. Indeed, it has earlier been shown that prosodic and semantic processing may be interactive (Astésano et al., 2004). However, to obtain more detailed conclusions on the N400 lateralization during shallow word processing, further investigations with more accurate source-localization methods have to be carried out.

It has earlier been proposed that the duration of the N400 priming effect may depend on the cognitive processes underlying it, the earlier part of the effect being related to automatic processing and the later part to controlled, attention-demanding processing (Koivisto & Revonsuo, 2001). In the present study, the N400 effect was statistically significant during all three latency windows of each task condition. Moreover, the latency of the N400 effect did not differ between the tasks nor were there any latency interactions between the tasks and the scalp distribution of the N400 effect. Thus, our results suggest that attentional modulation does not have an influence on the speed of semantic priming in the brain.

Conclusions

The present findings provide new evidence on the effects of attention on semantic processing of spoken language. The results show that semantic processing of speech, as revealed by the N400 effect, occurs even without effortful attention to speech, although the response is less strong than when the words are actively attended. When active attending of words is required, focusing on semantically irrelevant word features does not decrease the magnitude or the speed of semantic processing. Furthermore, attentional modulation has an impact on the spatial distribution of the N400 effect.

APPENDIX A. Stimulus Material in Finnish and English

Prime Word (Related)	*Prime Word (Unrelated)*	*Target Word*
REIKÄ (hole)	LANKA (thread)	AUKKO (gap)
VANTAA (a Finnish city)	TUPA (farmhouse)	ESPOO (a Finnish city)
KUUSI (spruce)	SILKKI (silk)	HAAPA (aspen)
MAKSA (liver)	POUTA (dry weather)	HAIMA (pancreas)
KAMPA (comb)	KÄÄRME (snake)	HARJA (brush)
LOHI (salmon)	JUNA (train)	HAUKI (pike)
UUNI (oven)	TANSKA (Denmark)	HELLA (stove)
POUTA (dry weather)	MÄNTY (pine)	HELLE (hot weather)
PORO (reindeer)	VENE (boat)	HIRVI (elk)
PIANO (piano)	RUOTSI (Sweden)	HUILU (flute)
KÄSI (hand)	VIILI (sour whole milk)	JALKA (foot)
KANI (rabbit)	SADE (rain)	JÄNIS (hare)
MERI (sea)	REIKÄ (hole)	JÄRVI (lake)
SEINÄ (wall)	PAITA (shirt)	KATTO (roof)
SAAPAS (boot)	PITSA (pizza)	KENKÄ (shoe)
MAITO (milk)	PEITTO (blanket)	KERMA (cream)
SUSI (wolf)	NAULA (nail)	KETTU (fox)
SYKSY (autumn)	SUIHKU (shower)	KEVÄT (spring)
RUUSU (rose)	KÄLY (sister-in-law)	KIELO (lily of the valley)
KOIRA (dog)	VISKI (whisky)	KISSA (cat)
HAUKKA (hawk)	PORRAS (step)	KOTKA (eagle)
KANA (chicken)	VANTAA (a Finnish city)	KUKKO (rooster)
MALJA (bowl)	LAMMAS (lamb)	KULHO (bowl)
PRONSSI (bronze)	VATSA (belly)	KULTA (gold)
MUKI (mug)	VALSSI (waltz)	KUPPI (cup)
MUTKA (bend)	KOIVU (birch)	KURVI (curve)
SUIHKU (shower)	KANI (rabbit)	KYLPY (bath)
NIEMI (cape)	OLUT (beer)	LAHTI (bay)
VENE (boat)	HAME (skirt)	LAIVA (ship)
KÄLY (sister-in-law)	MAKSA (liver)	LANKO (brother-in-law)
ITÄ (east)	KOIRA (dog)	LÄNSI (west)
VAUVA (baby)	LUMI (snow)	LAPSI (child)
KOIVU (birch)	KORVA (ear)	LEPPÄ (alder)
KÄÄRME (snake)	RAUTA (iron)	LISKO (lizard)

APPENDIX A *(continued)*

Prime Word (Related)	*Prime Word (Unrelated)*	*Target Word*
HAME (skirt)	MUIKKU (vendace)	MEKKO (dress)
JUNA (train)	PORO (reindeer)	METRO (subway)
TUPA (farmhouse)	JANO (thirst)	MÖKKI (cottage)
VAARI (grandfather)	PÖYTÄ (table)	MUMMO (grandmother)
HATTU (hat)	LOHI (salmon)	MYSSY (cap)
JANO (thirst)	PRONSSI (bronze)	NÄLKÄ (hunger)
KAULA (front of neck)	PIANO (piano)	NISKA (back of neck)
TANSKA (Denmark)	ANKKA (duck)	NORJA (Norway)
MUNKKI (monk)	NIEMI (cape)	NUNNA (nun)
PIISPA (bishop)	SEINÄ (wall)	PAAVI (pope)
TUNTI (hour)	VIULU (violin)	PÄIVÄ (day)
MAILA (racket)	MERSU (Mercedes-Benz)	PALLO (ball)
PITSA (pizza)	ITÄ (east)	PASTA (pasta)
NIITTY (meadow)	VELI (brother)	PELTO (field)
MARKKA (mark)	LUKKO (lock)	PENNI (penny)
VIILI (sour whole milk)	HIIRI (mouse)	PIIMÄ (sour curdled milk)
SÄÄRI (shin)	TUNTI (hour)	POHJE (calf)
KEITTO (soup)	SUSI (wolf)	PUURO (porridge)
LUMI (snow)	VAARI (grandmother)	RÄNTÄ (sleet)
PORRAS (step)	SOTA (war)	RAPPU (stairs)
SOTA (war)	HATTU (hat)	RAUHA (peace)
AUTO (car)	KAURA (oat)	REKKA (truck)
LAUKKU (bag)	HAUKKA (hawk)	REPPU (backpack)
HIIRI (mouse)	SYKSY (autumn)	ROTTA (rat)
NAULA (nail)	MAITO (milk)	RUUVI (screw)
RANSKA (France)	KÄSI (arm)	SAKSA (Germany)
LUKKO (lock)	RANSKA (France)	SALPA (bolt)
VATSA (belly)	KEITTO (soup)	SELKÄ (back)
VIULU (violin)	VARVAS (toe)	SELLO (cello)
AHVEN (perch)	VAUVA (baby)	SIIKA (powan)
LANKA (thread)	SAAPAS (boot)	SIIMA (line of a fishing rod)
MUIKKU (vendace)	KAULA (front of neck)	SILLI (herring)
KORVA (ear)	KESÄ (summer)	SILMÄ (eye)
VELI (brother)	MARKKA (mark)	SISKO (sister)
LEHMÄ (cow)	KUUSI (spruce)	SONNI (bull)
VARVAS (toe)	MERI (sea)	SORMI (finger)
ANKKA (duck)	MUTKA (bend)	SORSA (mallard)
SAUVA (stick)	UUNI (oven)	SUKSI (ski)

APPENDIX A (*continued*)

Prime Word (Related)	*Prime Word (Unrelated)*	*Target Word*
RUOTSI (Sweden)	LAUKKU (bag)	SUOMI (Finland)
PAITA (shirt)	KAMPA (comb)	TAKKI (coat)
KESÄ (summer)	POIKA (boy)	TALVI (winter)
MÄNTY (pine)	MUKI (mug)	TAMMI (oak)
VALSSI (waltz)	AHVEN (perch)	TANGO (tango)
RAUTA (iron)	RUUSU (rose)	TERÄS (steel)
PÖYTÄ (table)	MUNKKI (monk)	TUOLI (chair)
SADE (rain)	MALJA (bowl)	TUULI (wind)
POIKA (boy)	VIIKKO (week)	TYTTÖ (girl)
PEITTO (blanket)	KANA (chicken)	TYYNY (pillow)
KAURA (oat)	SAUVA (stick)	VEHNÄ (wheat)
OLUT (beer)	LEHMÄ (cow)	VIINI (wine)
SILKKI (silk)	AUTO (car)	VILLA (bishop)
VISKI (whisky)	NIITTY (meadow)	VODKA (vodka)
MERSU (Mercedes-Benz)	MAILA (racket)	VOLVO (Volvo)
LAMMAS (lamb)	PIISPA (bishop)	VUOHI (goat)
VIIKKO (week)	SÄÄRI (shin)	VUOSI (year)

Acknowledgments

This work, as part of the European Science Foundation EUROCORES Programme OMLL, was supported by funds from the Academy of Finland (grant 200522) and the EC Sixth Framework Programme under Contract no. ERAS-CT-2003-980409.

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