To Predict or Not to Predict: Influences of Task and Strategy on the Processing of Semantic Relations

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Abstract

■ We report a series of event-related potential experiments designed to dissociate the functionally distinct processes involved in the comprehension of highly restricted lexical–semantic relations (antonyms). We sought to differentiate between influences of semantic relatedness (which are independent of the experimental setting) and processes related to predictability (which differ as a function of the experimental environment). To this end, we conducted three ERP studies contrasting the processing of antonym relations (*black–white*) with that of related (*black–yellow*) and unrelated (*black–nice*) word pairs. Whereas the lexical–semantic manipulation was kept constant across experiments, the experimental environment and the task demands varied: Experiment 1 presented the word pairs in a sentence context of the form *The opposite of X is Y* and used a sensicality judgment. Experiment 2 used a word pair presentation mode and a lexical decision task. Experiment 3 also examined word pairs, but with an antonymy judgment task. All three experiments revealed a graded N400 response (unrelated > related > antonyms), thus supporting the assumption that semantic associations are processed automatically. In addition, the experiments revealed that, in highly constrained task environments, the N400 gradation occurs simultaneously with a P300 effect for the antonym condition, thus leading to the superficial impression of an extremely ''reduced'' N400 for antonym pairs. Comparisons across experiments and participant groups revealed that the P300 effect is not only a function of stimulus constraints (i.e., sentence context) and experimental task, but that it is also crucially influenced by individual processing strategies used to achieve successful task performance. ■

INTRODUCTION

Like other domains of higher cognition, language-based communication relies upon a successful interplay between previously processed information, information currently being processed, and the predictions arising from the combination of these two information sources. It is generally assumed that predictive processing behavior of this type is one of the keys to the efficiency of real-time language comprehension and, as such, that it applies at all levels of linguistic processing. For example, predictions have been shown to be operative in the phonological analysis of the ongoing speech stream (Connolly & Phillips, 1994), in the establishment of lexical–semantic relations (Kutas & Federmeier, 2000; Federmeier & Kutas, 1999), in basic processes of syntactic structure building (Stabler, 1994), and with respect to syntactic relations (Gibson, 1998). In cognitive neuroscience, predictive language processing has been examined primarily with respect to the lexical–semantic domain, thereby revealing consistent patterns of predictive processing behavior on the word (Van Petten, 1993), sentence (Kutas & Hillyard, 1980), and even discourse levels (Hagoort, Hald, Bastiaansen, & Petersson, 2004; van Berkum, Hagoort, & Brown, 1999). Within this domain, additional costs arising from the processing of unpredicted information or information that was not otherwise preactivated on the basis of previous processing steps have been associated with a specific electrophysiological correlate, the so-called N400 effect (i.e., a negative deflection over centroparietal electrodes between approximately 300 and 600 msec after critical stimulus onset and a maximal peak in the vicinity of 400 msec). Notably, this effect spans all of the previously described levels of processing in that it is observable for words, sentences, and texts. As such, the N400 has been regarded a general marker for integration difficulties as a function of the previous processing context.

Interestingly, this language-related effect of integration as a function of predictability differs markedly from the event-related potential (ERP) effect that is commonly associated with domain general processes of ''context updating,'' namely, the P300 effect (Picton, 1993; Donchin & Coles, 1988; for an alternative perspective, see Verleger, 1988). The P300 is a positive deflection with a maximal amplitude at approximately 300 msec and is typically classified into two subcomponents, the P3a and the P3b. Whereas the P3a has an anterior scalp

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distribution and is typically associated with the processing of novel stimuli, the P3b is characterized by a posterior distribution and is engendered by target items (Polich, 2004). In addition to these topographical differences, the P3a often shows a slightly shorter latency than the P3b. Thus, the N400 and the P300 appear to index functionally different levels of predictive processing via distinct electrophysiological characteristics. The existence of these different levels suggests that there should be a range of cognitive tasks that lead to a potential overlap of both processing domains and, thereby, of both components.

Indeed, a substantial portion of the early electrophysiological literature on word-level processing focused on the question of whether apparent modulations of the N400 should not rather be attributed to underlying differences in P300 effects (for discussion, see Rugg, 1990; Holcomb, 1988). This discussion was primarily centered around effects of word frequency and repetition and the general finding that highly frequent words and repeated words engender more positive-going ERP waveforms than their lower frequent and nonrepeated counterparts. From these studies, three general conclusions can be drawn: (a) There is evidence for a semantic modulation of the N400 component that is independent of other effects. (b) Nonetheless, apparent N400 modulations may be influenced by differences in the latency and/or amplitude of simultaneously evoked P300 effects. (c) P300 effects may follow N400 effects and thus show up with a latency from 500 msec onward. In this context, the strength of the interaction between the two components appears to depend at least in part on attentional aspects of processing that modulate the amplitude and latency of the P300 within the experimental environment (Holcomb, 1988).

With respect to higher level (i.e., relational) processing demands in language comprehension, the possible involvement of P300 effects is much more controversial. Whereas it is undisputed that late positive effects at the word level can be regarded as (decision-related) instances of P300s that follow the N400 (see, e.g., Chwilla, Kolk, & Mulder, 2000), there is a debate as to whether late positivities at the sentence level (P600/SPS) can also be interpreted as members of the P300 family (e.g., Osterhout & Hagoort, 1999; Coulson, King, & Kutas, 1998). Perhaps more importantly for the question under consideration, the possible occurrence of P300 effects within the N400 time window has only been discussed in the context of possible latency shifts within the P300. Thus, it was suggested that apparent modulations of N400 amplitude might be attributable solely to differences in P300 latency between the critical conditions (e.g., Curran, Tucker, Kutas, & Posner, 1993; Polich, 1985). By contrast, the possibility of a true component overlap between the N400 and the P300 within a single time window has received virtually no attention in the literature on relational semantic processing.

The literature does, however, provide some tentative indications that N400 effects at the relational level may not always be entirely due to reductions of the negativity for predicted stimuli, but may rather result from the co-occurrence of an N400 reduction and a P300 within the same time range. Within the extensive range of ERP studies discussed in Kutas and Federmeier's (2000) review of lexical–semantic processes during language comprehension, the effects engendered by a paradigm involving antonym relations (e.g., *black–white*) stands out. In contrast to all other studies, in which the morphology of the ERP components appears fully compatible with the standard functional interpretation that the N400 component is reduced when a stimulus is predictable or preactivated, the presentation of the second item in an antonym pair (Kutas & Iragui, 1998) appears to go beyond a mere reduction of the N400 in inducing a clear positive deflection within the same time range (for similar findings, see Bentin, 1987, and Federmeier & Kutas, 1999). Kutas and Iragui (1998) calculated differences between the ERP responses to antonyms (*white* in the context of ''The opposite of black'') and unrelated words (*peach* in the same context) and interpreted the maximal peak of the resulting difference wave as the N400 effect. This effect was interpreted functionally as reflecting semantic congruity and was used as an electrophysiological marker of age-related differences in semantic processing. In a similar manner, Bentin (1987) describes the ''negativity related to the expected antonym'' in his study as ''almost nonexistent.'' However, an alternative interpretation of the ERP pattern observed for antonyms may be that it results from the co-occurrence of two logically independent processes, namely, (a) a modulation of the degree of semantic association between two words and (b) the predictability of the antonym (e.g., *white*) as a target item following a prime such as ''the opposite of black.'' Whereas the former aspect engenders an N400 reduction for the antonym, the latter process gives rise to a P300 effect within the same time range as the N400. The superposition of these two effects could yield a surface pattern with the appearance of an ''extremely reduced'' N400 effect. If true, this alternative interpretation would lead to profound consequences for the interpretation of the results in question. With respect to the Kutas and Iragui study, for example, it raises the possibility that the age-related changes observed in the surface N400 effect might, in fact, stem from changes in the P300 (e.g., Yamaguchi & Knight, 1991) rather than in the N400. This would, of course, call for a fundamentally different interpretation of the neurophysiological effects of aging observed in the study in question.

The Present Studies

Although the account outlined above appears to provide an appealing solution to the differing morphologies for

N400 modulations in various contexts, the two components that appear to be involved (N400, P300) are difficult to disentangle on the basis of previous findings. In the present article, we report a series of three ERP studies designed to provide a differential modulation of the functionally distinct processes involved in the processing of antonym relations. In particular, we sought to dissociate between influences of semantic relatedness, which should be independent of the particular experimental environment, and processes related to predictability, which can be assumed to differ as a function of the experimental context (e.g., mode of presentation, task, etc.). To this end, we examined the processing of antonym relations in three different experimental settings, thus keeping semantic relatedness constant while varying the degree of predictability of the second element on the basis of different task demands and experimental environments.

In Experiment 1, participants read sentences of the form *The opposite of black is white/yellow/nice* and were asked to perform a sensicality judgment. The experimental design thereby provided a parametric modulation of semantic association (antonyms > within-category violations such as *yellow* > across-category violations such as *nice*) in a maximally restricted—and therefore predictive—setting. Thus, the combination of the particular task and the sentence context induced a strong and *unique* prediction for the sentence-final antonym. Experiment 1 therefore aimed to replicate Kutas and Iragui's (1998) finding of a graded N400 effect for antonym relations that includes a clear positive deflection for the antonym condition (see also Figure 1B in Kutas & Federmeier, 2000). In addition, a parametric semantic manipulation was introduced to allow for a separation between true effects of semantic association and effects related to the predictability of the second item in an antonym pair.

Experiment 2 examined the processing of the identical parametric semantic modulation in a maximally unrestricted setting with respect to task- and environment-related predictability. To this end, the critical stimuli (*black–white/yellow/nice*) were presented as word pairs and interspersed with word pairs containing a pseudoword in first or second position. In this study, participants were asked to perform a lexical decision task (i.e., to decide whether a pseudoword had occurred within the word pair they had just read), thereby rendering the semantic modulation entirely irrelevant to successful task performance of the task.

Finally, Experiment 3 aimed to induce an intermediate degree of predictability with respect to the processing of the critical antonym pairs. Thus, the same mode of presentation as in Experiment 2 was chosen (i.e., presentation of single words as word pairs), albeit without the inclusion of additional material containing pseudowords. Moreover, an antonymy decision task was used, thereby again rendering the semantic relation between the words relevant for task performance. Nonetheless, because the word pairs were not embedded in a restrictive sentence frame, we reasoned that the degree of predictive processing would be reduced in this study as opposed to Experiment 1 (i.e., here, predictions can be based only on the task as opposed to task plus sentence frame).

On the basis of these manipulations, and assuming that the degree of semantic association and the degree of predictability are indeed functionally and neurophysiologically independent of one another, we can formulate two basic hypotheses. First, the degree of predictability for the second word in an antonym relation should give rise to modulations of the P300. This component should be observable in the same time range as the N400 and should vary in strength across the three experiments such that it is strongest in Experiment 1, weakest in Experiment 2, and of intermediate strength in Experiment 3. Second, as the degree of semantic association is held constant across the three experiments, we expect to observe a modulation of the N400 that is independent of task and experimental environment. As the "N400 reduction" for the antonyms may co-occur with a positive deflection (P300) in the same time range (see Hypothesis 1), the best measure for the effects of semantic relatedness across experiments should be the relative difference in the N400 time window between the within- and across-category violations. Finally, in view of previous findings on the processing of (target) pseudowords, the pseudowords in Experiment 2 can be expected to elicit an increased N400 effect followed by a late positivity. Recognizing a pseudoword as an inexistent word requires lexical search processes, thereby increasing N400 amplitude. The task-related P300 effect should therefore be delayed until the completion of this search and, thereby, to the post-N400 time range (Bentin, McCarthy, & Wood, 1985).

METHODS

Materials

All experiments used three critical conditions: antonym pairs, pairs of related words and pairs of unrelated words. In Experiment 1, these critical stimuli were embedded in a fixed sentence context of the form *The opposite of X is Y*, with X and Y instantiating the manipulation of interest (see Table 1). In Experiments 2 and 3, the critical stimuli were presented as word pairs. Table 1 further shows that the critical stimuli did not differ in frequency, $F(2,237) = 1.43$, $p > .24$, or word length, $F(2,237) = 1.70$, $p > .18$.

Eighty sets (triplets) of the three conditions (antonyms, related, unrelated) were created, thus resulting in a total of 240 critical stimuli. To balance the number of "yes" and "no" responses in Experiments 1 and 3, four lists of 160 critical items were constructed (consisting of 80 antonym pairs and 40 pairs for each of the two

Table 1. Example Stimuli for Experiments 1–3

Condition	Example	*Length, Mean No. of Syllables (SD)*	*Frequency (SD)*	*Relatedness, Mean (SD)*	*Antonymy, Mean (SD)*
A. Antonyms	*Schwarz–weiss*	1.85 (0.80)	34,781.99 (53,684.45)	2.10 (0.83)	1.21 (0.19)
	Black–white				
B. Related	*Schwarz–gelb*	2.02 (0.75)	19,303.10 (53,631.92)	3.05 (0.77)	4.80 (0.73)
	Black–yellow				
C. Nonrelated	*Schwarz–nett*	1.78 (0.60)	15,731.45 (10,7226.5)	6.35 (0.61)	6.93 (0.16)
	Black–nice				

In Experiment 1, the critical word pairs were presented in a fixed sentence context (*Das Gegenteil von X ist Y*, "The opposite of X is Y"). Experiments 2 and 3 used the same critical word pairs in the absence of a sentence context. The third and fourth columns list the mean length and frequency of the critical second word of the pairs. Frequencies consisted of raw occurrence frequencies within the corpus of the Project Deutscher Wortschatz (wortschatz.uni-leipzig.de). The final two columns show the results of a norming study (n = 22) designed to test the degree of relatedness and antonymy of the critical materials (scale 1 to 7; see the section Questionnaire Pretest).

mismatch conditions). Thus, each list contained all 80 antonym relations, whereas only half of the total materials were used for each list for the other two conditions. In Experiment 2, four lists of 120 critical items were constructed (40 pairs from each condition), as there was no need for a 1:1 ratio of antonyms and nonantonyms in view of the different task (see below). Rather, the critical materials for Experiment 2 were supplemented by 160 additional word pairs containing a pseudoword in either first (80 pairs) or second position (80 pairs). These were spread across the four lists of critical items such that each list always contained 40 pairs with a pseudoword in the first position and 40 pairs with a pseudoword in the second position. Thus, each list in Experiment 2 comprised a total of 200 word pairs.

Questionnaire Pretest

To ensure that the critical items indeed differed with respect to antonymy and semantic relatedness in the desired way, we conducted a questionnaire pretest.

Twenty-two students (13 women, 9 men) of the University of Leipzig participated in the questionnaire study. Participants were randomly assigned to two equally sized groups (Group A: 5 women; age 25.5 [2.62] years, mean [SD]; range 21–29 years; Group B: 8 women; age 23.4 [3.59] years, mean [SD]; range 17–28 years). There was no significant difference with regard to age between Groups A and B, $F(1,10) = 2.06, p < .19$.

Each questionnaire comprised 80 randomized word pairs, of which 40 were antonym pairs (ANT), 20 were related category word pairs (REL), and 20 were nonrelated category word pairs (NON). Four different versions were constructed such that no single word was repeated within a list. Lists were identical for Groups A and B and the questionnaires differed solely in instruction.

Both groups were instructed to read a given word pair carefully and to then rate the relationship between the two words on a 7-point scale by circling a number between 1 and 7. Whereas participants in Group A were instructed to judge the *degree of antonymy*, that is, the degree to which a given word pair can be considered an antonym pair (1 = *optimal antonym*, 7 = *not at all an antonym*), participants in Group B were asked to judge the *degree of relatedness* between the two words (1 = *very strongly related*, 7 = *completely unrelated*).

The mean rating scores for both groups are shown in Table 1. A repeated measures analysis of variance (ANOVA) including the within-participants factor Condition (antonym vs. related vs. unrelated) and the between-participants factor Group (antonymy judgment vs. relatedness judgment) revealed main effects of Group, $F_1(1,10) = 7.29$, $p < .02$; $F_2(1,79) = 35.56$, $p < .01$, and Condition, $F_1(2,20) = 448.06$, $p < .01$; $F_2(2,158) = 1327.78$, $p < .01$, and a significant Group × Condition interaction, $F_1(2,20) = 31.26, p < .01$; $F_2(2,158) = 83.56, p < .01$.

As the main interest in the task manipulation within the pretest lay in examining whether the rating difference between the antonym pairs and the related word pairs would be modulated by the task requirements, we performed an additional analysis involving the within-participants factor Category (antonyms vs. related word pairs) and the between-participants factor Group. This analysis also revealed a significant Category × Group interaction, $F_1(1,10) = 41.55, p < .01$; $F_2(1,79) = 153.11$, $p < .01$. Nevertheless, resolving interaction by Group showed that the difference between antonyms and related word pairs reached significance for both Group A, $F_1(1,10) = 231.41, p < .01$; $F_2(1,79) = 585.42, p < .01$, and Group B, $F_1(1,10) = 8.18, p < .02$; $F_2(1,79) = 55.73$, $p < .01$. An examination of the F values suggests that the significant interaction Category × Group was due to a much smaller difference between both categories under the instructions emphasizing relatedness in comparison to the antonymy judgement instruction.

In summary, the results of the pretest confirmed that our stimulus materials differed along the two critical dimensions *antonymy* and *relatedness*. In addition, they showed that the perceived difference between the antonyms and the related word pairs is larger under task conditions emphasizing the antonym relation.

Participants

Seventeen undergraduate students from the University of Marburg participated in each of the three experiments (Experiment 1: 13 women, mean age 23.7 years, range 20–28 years; Experiment 2: 11 women; mean age 24.6 years; range 20–31 years; Experiment 3: 11 women; mean age 23.2 years, range: 20–29 years). No participant took part in more than one of the three studies. All participants were right-handed (as assessed by an adapted and modified German version of the Edinburgh Handedness Inventory; Oldfield, 1971), were monolingual native speakers of German, and had normal or corrected-to-normal vision.

Procedure

In Experiment 1, sentences were presented visually in the center of a computer screen in a word-by-word manner. Each trial began with the presentation of an asterisk (2000 msec) in order to fixate participants' eyes at the center of the screen and to alert them to the upcoming presentation of the sentence. Single words were presented for 350 msec with an interstimulus interval (ISI) of 200 msec. The presentation of a sentence was followed by 650 msec of blank screen, after which participants were required to complete an antonym sentence verification task (signaled by the presentation of a question mark). This task involved judging whether the proposition expressed by the sentence was right or wrong. Subjects responded by pressing the left or right mouse button for yes or no (maximal reaction time, 3000 msec). After a participant's reaction, there was an intertrial interval (ITI) of 2250 msec before the next trial started.

In Experiments 2 and 3, the critical word pairs were presented out of sentence context. The first word (prime) was presented for 400 msec with an ISI of 400 msec, whereas the second word (target) was presented for 350 msec with an ISI of 650 msec (preceding the task). In Experiment 2, participants were required to complete a lexical decision task, which involved judging whether one of the two words was a pseudoword or not. In Experiment 3, participants judged whether the word pairs were antonyms or not. In both cases, the left and right mouse buttons corresponded to yes or no, respectively, and the reaction times were restricted to 3000 msec. Between the trials there was an ITI of 1400 msec.

Participants were asked to avoid movements and eyeblinks during the presentation of the sentences/word pairs. All experimental sessions began with a short training session followed by four experimental blocks, between which the participants took short breaks. Each experimental session lasted approximately 2 hr (including electrode preparation).

Electroencephalograms (EEGs) were recorded by means of 27 sintered Ag/AgCl electrodes fixed at the scalp by means of an elastic cap (Easy Cap International, Herrsching-Breitbrunn, Germany). The ground electrode was positioned at C2. Recordings were referenced to the left mastoid, but re-referenced off-line to linked mastoids. Electrooculograms (EOGs) were monitored by means of electrodes placed at the outer canthus of each eye for the horizontal EOG and above and below the participant's left eye for the vertical EOG. Electrode impedances were kept below 5 kΩ. All EEG and EOG channels were amplified using a BrainVision BrainAmp amplifier (time constant, 0.9 sec; high cutoff, 70 Hz) and recorded with a digitization rate of 250 Hz.

Data Analysis

For each experiment, average ERPs were calculated per condition per participant from 334 msec before the onset of the critical stimulus item (i.e., the second word of the critical stimulus pairs) to 1000 msec after onset, before grand averages were computed over all participants. Trials for which the task was not performed correctly were excluded, as were trials containing ocular or other artifacts. For the statistical analysis, multivariate analyses of variance were computed using the condition factor Type (antonyms vs. related vs. unrelated) and the topographical factors Region of Interest (ROI) for the lateral and midline electrodes. Lateral regions of interest were defined as follows: left anterior (F7, F3, FC5), left posterior (P7, P3, CP5), right anterior (F8, F4, FC6), and right posterior (P8, P4, CP6). For the midline electrodes, each electrode (FZ, CZ, PZ, and OZ) was treated as an ROI of its own. All statistical analyses were carried out in a hierarchical manner; that is, only significant interactions ($p < .05$) were resolved. To avoid Type I errors resulting from violations of sphericity, the correction proposed by Huynh and Feldt (1970) was applied. The probability level for planned comparisons was adjusted according to a modified Bonferroni procedure (Keppel, 1991).

RESULTS

Experiment 1: Sentence Context

Behavioral Data

The sensicality judgment task yielded the following mean error rates and reaction times, respectively (standard deviations in parentheses): antonyms—1.54 (1.84), 478.38 (143.75); related—5.88 (3.30), 533.44 (166.62); unrelated—0.29 (0.80), 440.45 (119.05).

For the error rates, a repeated measures ANOVA revealed a main effect of Type, $F_{\mathrm{Subj}}(2,32) = 28.75$, $p < .001$; $F_{\mathrm{Item}}(2,158) = 22.05$, $p < .001$. Planned comparisons showed a significant difference between all pairs of conditions: antonyms versus unrelated word pairs, $F_{\text{Subj}}(1,16) = 6.48$, $p < .03$; $F_{\text{Item}}(1,79) = 6.38$, $p < .02$; antonyms versus related word pairs, $F_{\text{Subj}}(1,16) = 20.19$, $p < .001$; $F_{\text{Item}}(1,79) = 17.78$, $p < .001$; and related versus unrelated word pairs, $F_{\text{Subj}}(1,16) = 50.23$, $p < .001$; $F_{\text{Item}}(1,79) = 37.06$, $p < .001$.

Analysis of the reaction times again showed a main effect of Type, $F_{\text{Subj}}(2,32) = 10.60$, $p < .001$; $F_{\text{Item}}(2,158) = 9.40$, $p < .003$. The planned comparisons showed the following effects: antonyms versus unrelated word pairs, $F_{\text{Subj}}(1,16) = 11.86$, $p < .004$; $F_{\text{Item}}(1,79) = 8.55$, $p < .006$; antonyms versus related word pairs, $F_{\text{Subj}}(1,16) = 5.03$, $p < .04$; $F_{\text{Item}}(1,79) = 7.39$, $p < .01$; and related versus unrelated word pairs, $F_{\text{Subj}}(1,16) = 16.85$, $p < .002$; $F_{\text{Item}}(1,79) = 11.32$, $p < .002$.

In summary, the behavioral data showed the lowest error rates and fastest reaction times for the unrelated condition and the highest error rates and slowest reaction times for the related condition. The antonym condition lay between the other two conditions in both cases.

ERP Data

Grand average ERPs at the position of the critical (sentence final) word are shown in Figure 1.

As shown in Figure 1, the three conditions differed from one another in two time windows. In the N400 time window, unrelated stimuli engendered more negative-going ERP waveforms than did related stimuli, which, in turn, engendered more negative ERP responses than did the antonyms. Furthermore, and as predicted, antonyms elicited a pronounced parietal positive peak within the N400 time window. Following the N400, the two nonantonym conditions elicited broadly distributed positivities. For the related condition, this effect had an anterior distribution, whereas in the unrelated condition, it was more posterior.

On account of the visual inspection of the data, the statistical analyses were conducted in two time windows: 240–440 (N400) and 500–750 (late positivity) msec. Repeated measures ANOVAs for the N400 time window revealed highly reliable main effects of Type and interactions Type × ROI for both lateral electrode sites, Type: $F(2,32) = 51.83$, $p < .001$; Type × ROI: $F(6,96) = 21.83$, $p < .001$, and midline electrode sites, Type: $F(2,32) = 64.63$, $p < .001$; Type × ROI: $F(6,96) = 11.96$, $p < .001$. Further analyses within each ROI showed reliable effects of Type in all regions: minimal $F(2,32) = 4.95$ for the left anterior ROI; maximal $F(2,32) = 101.24$ at Pz. Planned comparisons for antonyms versus unrelated word pairs also reached significance in all regions, minimal $F(1,16) = 4.48$ for the left anterior ROI; maximal

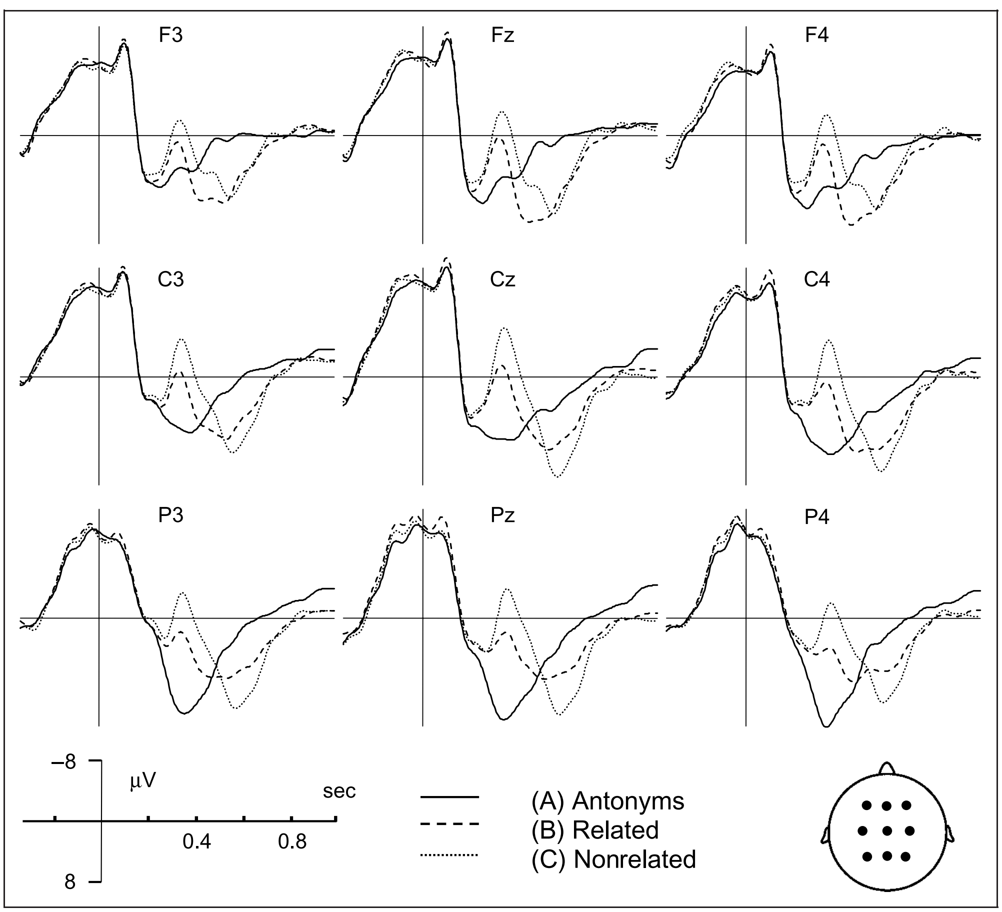


Figure 1. Grand average ERPs for the antonyms and related and unrelated conditions in Experiment 1 (onset at the vertical bar). Negativity is plotted upward.

$F(1,16) = 143.84$ at Pz, as did the planned comparisons for related versus unrelated word pairs, minimal $F(1,16) = 11.51$ at Fz; maximal $F(1,16) = 84.60$ for the right posterior ROI. The planned comparisons between antonyms and related word pairs reached significance in all but two regions: left anterior ROI and Fz; minimal significant $F(1,16) = 7.99$ for the right anterior ROI and maximal $F(1,16) = 79.87$ at Pz.

Within the time window for the late positivity, the statistical analysis again revealed significant main effects of Type and Type × ROI at lateral, Type: $F(2,32) = 25.82$, $p < .001$; Type × ROI: $F(6,96) = 12.68$, $p < .001$, and midline sites, Type: $F(2,32) = 21.51$, $p < .001$; Type × ROI: $F(6,96) = 9.06$, $p < .001$. The analyses of Type within each ROI yielded reliable effects in all regions: minimal $F(2,32) = 11.96$ at Oz; maximal $F(2,32) = 30.72$ for the left posterior ROI. The planned comparisons showed significant effects in all regions for antonyms versus unrelated words, minimal $F(1,16) = 11.50$ for the right anterior ROI and maximal $F(1,16) = 52.97$ for the left posterior ROI, as well as for antonyms versus related words, minimal $F(1,16) = 5.52$ at Oz; maximal $F(1,16) = 27.41$ for the right posterior ROI. The planned comparisons for related versus unrelated words were significant at all but three sites: left and right anterior ROI and Fz; minimal significant $F(1,16) = 8.66$ for the right posterior ROI and maximal $F(1,16) = 21.05$ for the left posterior ROI.

To summarize, Experiment 1 showed a parametric modulation within the N400 time window, with ERPs to unrelated word pairs more negative-going than those to related word pairs, which, in turn, were more negative than those elicited by antonyms. Moreover, the morphology of the waveforms showed a positive peak for antonyms within this time window. This pattern therefore replicates previous results in the domain of antonym processing (Kutas & Federmeier, 2000; Kutas & Iragui, 1998). In addition, and in contrast to previous studies, the two nonantonym conditions engendered late positivities in response to the antonym stimuli. Although this late effect had a posterior maximum for the unrelated condition, its topographical distribution was more anterior for the related stimuli.

Experiment 2: Word Pairs with a Lexical Decision Task

Behavioral Data

The mean error rates and reaction times, respectively, for the lexical decision task were as follows (standard deviations in parentheses): antonyms—0.73 (1.47), 467.88 (204.71); related—0.88 (1.23), 506.96 (251.24); unrelated—1.62 (2.49), 524.94 (245.58); pseudowords—2.06 (2.54), 519.56 (288.45).

For the error rates, a repeated measures ANOVA revealed no main effect of Type, $F_{Subj}(3,48) = 1.55, p > .24$; $F_{Item}(3,237) = 2.16, p > .13$.

By contrast, the analysis of the reaction times showed a main effect of Type, $F_{Subj}(3,48) = 4.15, p < .03$; $F_{Item}(3,237) = 4.80, p < .004$. The planned comparisons yielded the following effects: antonyms versus unrelated word pairs, $F_{Subj}(1,16) = 11.52, p < .005$; $F_{Item}(1,79) = 15.34, p < .001$; antonyms versus related word pairs, $F_{Subj}(1,16) = 7.04, p < .02$; $F_{Item}(1,79) = 6.45, p < .02$; related versus unrelated word pairs, $F_{Subj}(1,16) = 3.30, p < .09$; $F_{Item}(1,79) = 1.82, p < .19$; antonyms versus pseudowords, $F_{Subj}(1,16) = 3.96, p < .07$; $F_{Item}(1,79) = 7.03, p < .02$; related versus pseudowords, $F_{Subj}(1,16) < 1$; $F_{Item}(1,79) < 1$; unrelated versus pseudowords, $F_{Subj}(1,16) < 1$; $F_{Item}(1,79) < 1$.

In summary, the behavioral data show no difference in error rates. However, the antonym condition yielded the fastest reaction times, whereas pseudowords and the unrelated condition showed the slowest reaction times. The reaction times for the related condition lay in-between these two extremes.

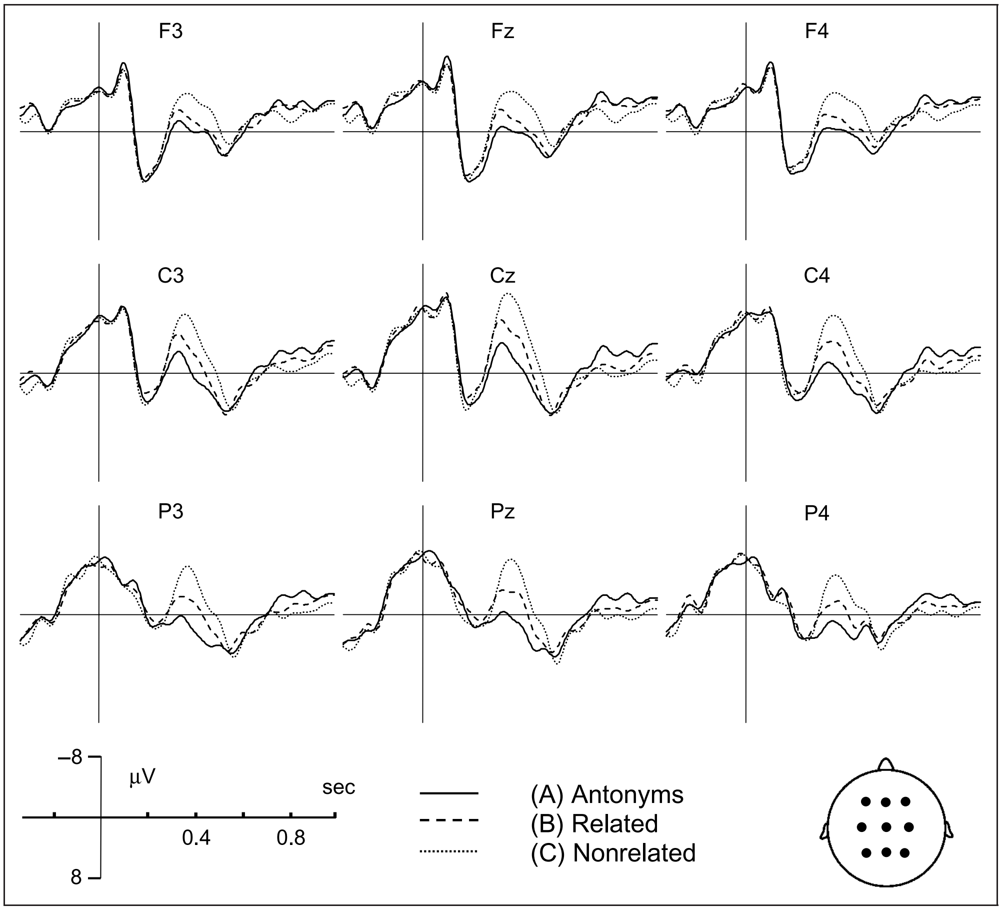
ERP data

Figures 2 and 3 show grand average ERPs at the position of the critical second word for the three conditions examined in Experiment 1 and antonyms versus unrelated word pairs versus pseudowords, respectively. From Figure 2, it is apparent that the gradation of the N400 observed in Experiment 1 (unrelated > related > antonyms) was also observable in Experiment 2. In contrast to Experiment 1, however, the antonym condition did not give rise to a positive deflection within the N400 time window. In addition, no late positive effects were observed in the comparison of the three critical conditions.

With respect to the pseudowords in second position, Figure 3 indicates that these did not differ from the unrelated condition within the N400 time window, that is, pseudowords and unrelated words evoked an N400 of similar amplitude in comparison to the antonyms. However, the two conditions differ strikingly in a later time window: Only pseudowords engendered a late positivity following the N400.

All of these descriptive observations were confirmed by the statistical analysis of the data. ANOVAs for the N400 time window (270–470 msec) showed highly reliable main effects of Type at both lateral, $F(3,48) = 20.05$, $p < .001$, and midline sites, $F(3,48) = 20.87$, $p < .001$, and a significant Type × ROI interaction for the midline electrodes, $F(9,144) = 4.37$, $p < .005$. The resolution of the main effect of Type at lateral electrode sites revealed significant effects for all contrasts but one: unrelated versus pseudowords; minimal significant $F(1,16) = 11.66$ for the contrast between related word pairs and pseudowords, maximal $F(1,16) = 36.15$ for the contrast between antonyms versus unrelated word pairs. Further analyses of Type in each ROI for the midline electrodes showed reliable effects at all sites: minimal $F(9,144) = 10.07$ at Fz and maximal $F(9,144) = 20.02$

Figure 2. Grand average ERPs for antonyms and related and unrelated category conditions in Experiment 2 (onset at the vertical bar). Negativity is plotted upward.



at Pz. The planned comparisons between antonyms and unrelated words reached significance at all sites, minimal $F(1,16) = 18.32$ at Fz, maximal $F(1,16) = 40.47$ at Pz, as did the planned comparisons between antonyms and related word pairs, minimal $F(1,16) = 7.15$ at Fz, maximal $F(1,16) = 43.61$ at Pz; the planned comparisons between related and unrelated word pairs, minimal $F(1,16) = 11.02$ at Pz, maximal $F(1,16) = 12.34$ at Cz; and the planned comparisons between antonyms and pseudowords, minimal $F(1,16) = 10.41$ at Fz, maximal $F(1,16) = 41.16$ at Pz. The planned comparison between related words and pseudowords only reached significance at Pz, $F(1,16) = 6.11$, whereas the comparison between unrelated words and pseudowords was not significant at any electrode. ANOVAs for the late positivity time window (520–770 msec) revealed significant effects of Type and Type × ROI at both lateral, Type: $F(3,48) = 12.83$, $p < .001$; Type × ROI: $F(9,144) = 5.61$, $p < .005$, and midline electrodes, Type: $F(3,48) = 11.21$, $p < .005$; Type × ROI: $F(9,144) = 6.02$, $p < .001$. Analyses of Type within each ROI showed reliable effects in all regions, minimal $F(9,144) = 4.46$ for the right anterior ROI, maximal $F(9,144) = 16.64$ for the right posterior ROI. The planned comparisons for antonyms versus unrelated words and antonyms versus related words showed no significant effects, whereas the planned comparison for related versus unrelated words only showed a reliable difference at Oz, $F(1,16) = 6.68$. In contrast, the planned comparisons for antonyms versus pseudowords revealed reliable effects at all sites, minimal $F(1,16) = 5.79$ at Oz, maximal $F(1,16) = 17.43$ for the right posterior ROI, as did the planned comparisons for related words versus pseudowords, minimal $F(1,16) = 5.82$ for the right anterior ROI, maximal. $F(1,16) = 21.18$ for the right posterior ROI, and those for unrelated words versus pseudowords, minimal $F(1,16) = 8.56$ at Oz, maximal $F(1,16) = 23.60$ for the right posterior ROI.

In summary, Experiment 2 revealed two major differences in comparison to Experiment 1. On the one hand, there was no early positive deflection for the antonym condition. On the other hand, the two nonantonym nonpseudoword conditions did not show a late positivity in comparison to the antonyms. By contrast, the pseudowords in second position, which showed a very similar N400 effect to the nonrelated word pairs, engendered a late positivity.

The presence or absence of positivity effects in our critical conditions thus appears to depend crucially upon the experimental environment in which the stimuli are presented (i.e., constraining sentence context plus a task focusing on the antonym relation in Experiment 1 versus unconstraining word pairs plus a lexical

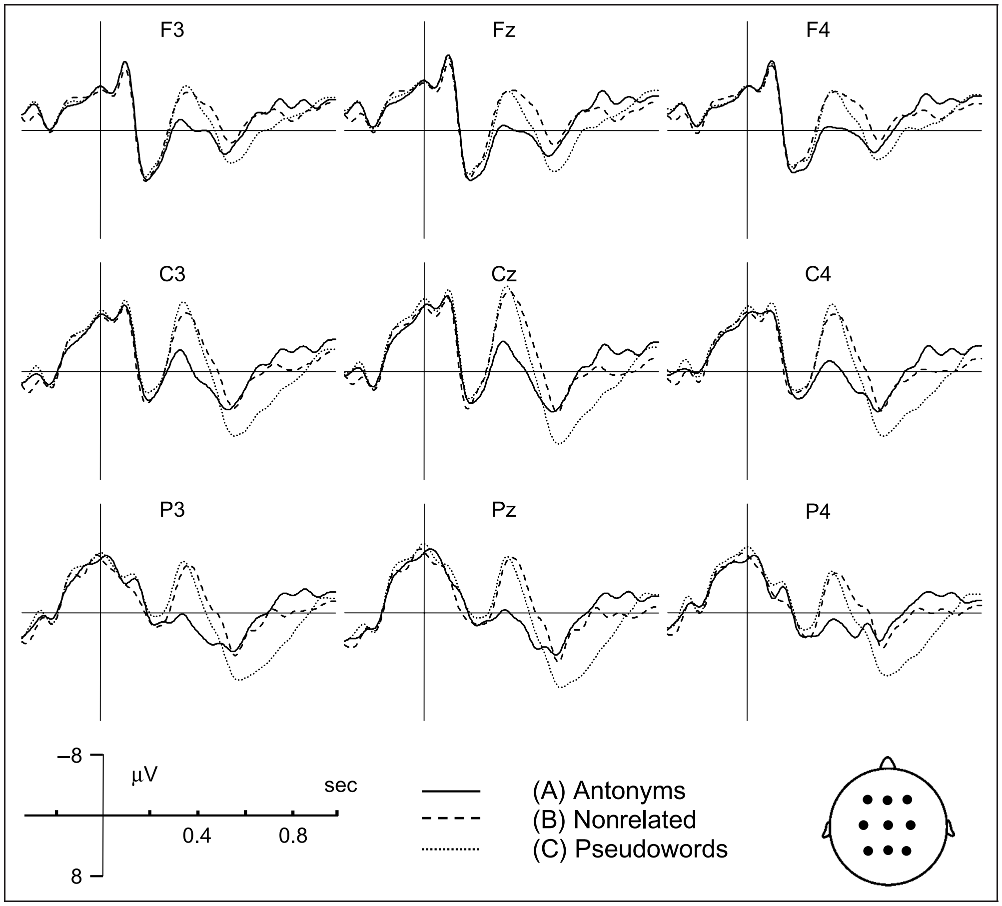


Figure 3. Grand average ERPs for pseudowords in second position, antonyms, and the unrelated condition in Experiment 2 (onset at the vertical bar). Negativity is plotted upward.

decision task in Experiment 2). As both the task and the experimental setting (i.e., constraining versus nonconstraining context) worked in the same direction in these two experiments, the question arises of how the processing system would respond to an intermediary situation. This issue was examined in Experiment 3 by presenting word pairs with an antonymy judgment task. If the difference between Experiments 1 and 2 was wholly determined by either the sentence context or the experimental task, we should expect the results of Experiment 3 to pattern either with Experiment 1 (if only the task is decisive) or with Experiment 2 (if the sentence context is the crucial parameter).

Experiment 3: Word Pairs with an Antonymy Judgment

Behavioral Data

The antonymy judgment task yielded the following mean error rates and reaction times, respectively (standard deviations in parentheses): antonyms—1.69 (1.87), 457.25 (153.04); related—4.56 (4.78), 505.85 (146.72); unrelated—0.29 (0.83), 444.14 (135.23).

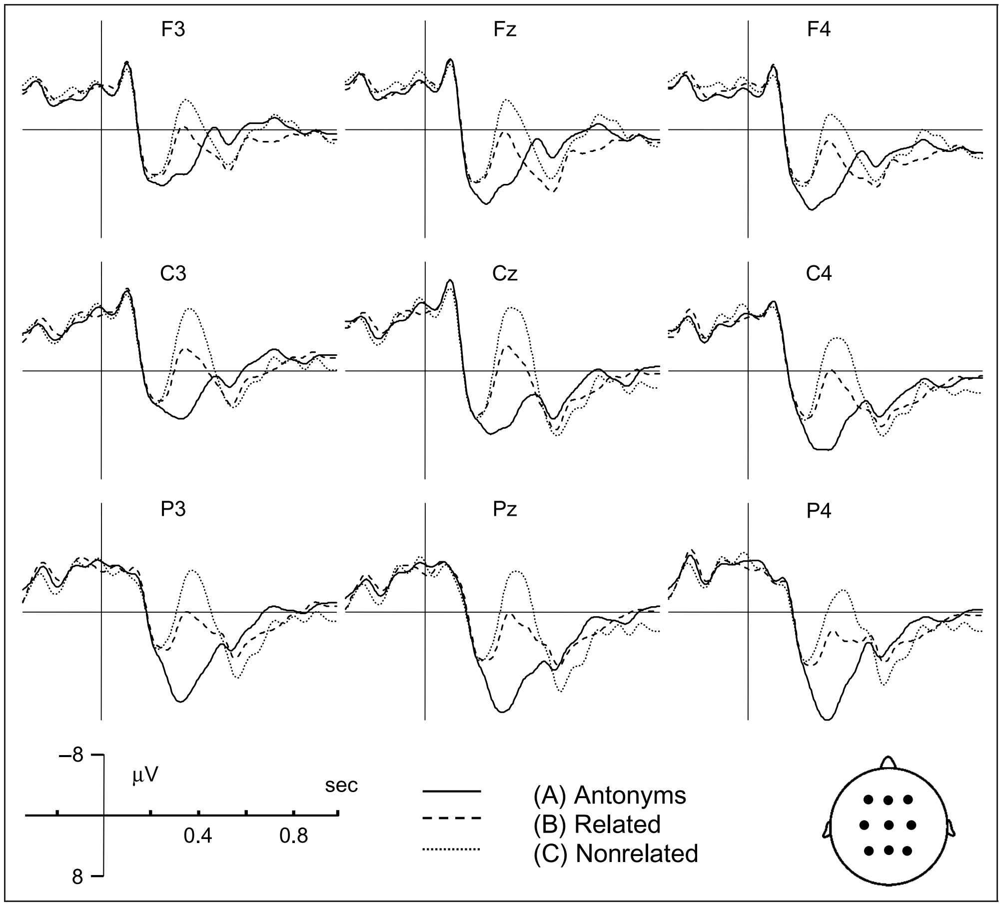
The statistical analysis of the error rates for the antonym judgment task revealed a significant main effect of Type, $F_{Subj}(2,32) = 10.34, p < .001$; $F_{Item}(2,158) = 14.76$, $p < .001$. Planned comparisons showed significant differences between all pairs of condition: antonyms versus unrelated word pairs, $F_{Subj}(1,16) = 8.14$, $p < .02$; $F_{Item}(1,79) = 4.16$, $p < .05$; antonyms versus related word pairs, $F_{Subj}(1,16) = 6.03$, $p < .03$; $F_{Item}(1,79) = 12.63$, $p < .002$; related versus unrelated word pairs, $F_{Subj}(1,16) = 15.98$, $p < .002$; $F_{Item}(1,79) = 17.92$, $p < .001$.

The analysis of the reaction times again showed a significant main effect of Type, $F_{Subj}(2,32) = 15.77, p < .001$; $F_{Item}(2,158) = 11.29$, $p < .001$. Planned comparisons revealed the following effects: antonyms versus unrelated word pairs ($p_{Subj} > .3$; $F_{Item} < 1$); antonyms versus related word pairs, $F_{Subj}(1,16) = 13.93$, $p < .003$; $F_{Item}(1,79) = 10.96$, $p < .002$; related versus unrelated word pairs, $F_{Subj}(1,16) = 29.00, p < .001$; $F_{Item}(1,79) = 20.49, p < .001$.

ERP Data

Grand average ERPs for the three critical conditions in Experiment 3 are shown in Figure 4. The figure suggests that the pattern in the present experiment is rather similar to that observed in Experiment 1: There is a graded N400 effect (unrelated > related > antonyms) in combination with a positive deflection for the antonym

Figure 4. Grand average ERPs for antonyms and related and unrelated conditions in Experiment 3 (onset at the vertical bar). Negativity is plotted upward.



condition within the same time window as well as a late positivity for the two nonantonym conditions.

These observations were confirmed by the statistical analysis for the N400 and late positivity time windows, respectively. ANOVAs for the N400 time window (270–470 msec) revealed highly reliable main effects of Type and Type × ROI interactions at both lateral, Type: $F(2,32) = 3.75$, $p < .01$; Type × ROI: $F(6,96) = 12.39$, $p < .001$, and midline electrode sites, Type: $F(2,32) = 44.86$, $p < .001$; Type × ROI: $F(6,96) = 14.44$, $p < .001$. Further analyses of Type within each ROI showed reliable effects in all regions: minimal $F(2,32) = 9.06$ for the left anterior ROI, maximal $F(2,32) = 59.28$ at Oz. The planned comparisons for antonyms versus unrelated word pairs also reached significance in all regions, minimal $F(1,16) = 12.00$ for the left anterior ROI, maximal $F(1,16) = 71.85$ at Oz, as did the planned comparisons for related versus unrelated word pairs, minimal $F(1,16) = 8.23$ for the left anterior ROI, maximal $F(1,16) = 42.24$ at Oz. The planned comparisons for antonyms versus related word pairs were significant at all sites but one, left anterior ROI; minimal significant $F(1,16) = 8.77$ at Fz and maximal $F(1,16) = 45.67$ at Oz. ANOVAs for the late positivity time window (510–760 msec) revealed significant effects of Type and Type × ROI for the lateral electrodes and a significant Type × ROI interaction for the midline electrodes. The analyses of Type in each ROI showed reliable differences in all regions except the left anterior ROI, Cz, Pz, and Oz, minimal significant $F(2,32) = 3.14$ for the right anterior ROI, maximal $F(2,32) = 13.45$ for the left posterior ROI. Planned comparisons for the significant regions showed significant differences between antonyms and unrelated words only in the left posterior ROI, $F(1,16) = 29.60$, and the right posterior ROI, $F(1,16) = 7.62$. Furthermore, the planned comparisons for antonyms versus related word pairs only revealed significant effects in the left posterior ROI, $F(1,16) = 11.29$, and at Fz, $F(1,16) = 6.10$. Finally, planned comparisons for related versus unrelated word pairs reached significance within the right anterior ROI, $F(1,16) = 6.27$, and at Fz, $F(1,16) = 6.78$. Thus, although all of the effects observed via visual inspection reached statistical significance, the overall data pattern appears to suggest that the positivity effects were somewhat weaker than those reported for Experiment 1.

In order to investigate more closely why the late positivity may have been somewhat attenuated in the present experiment in comparison to Experiment 1, we examined the individual participant averages for the three critical conditions. The rationale for this post hoc comparison was based on the assumption that individual participants may have adopted different strategies in processing the stimuli of Experiment 3, thus leading them to show either a similar pattern to Experiment 1 or to Experiment 2. We thus classified participants according to whether they showed a difference between the two nonantonym conditions and the antonym condition in the late positivity time window or not. The result of this classification is shown in Figure 5.

Strikingly, the group split based on the late positivity showed a further and unexpected result: As is immediately apparent from Figure 5, only the subset of participants that showed a late positivity for the two nonantonym conditions also showed a positive deflection for the antonyms in the N400 time window. By contrast, the second participant group showed no positivity effects whatsoever. To confirm this descriptive result, we carried out an additional statistical analysis, in which we compared difference waves between antonyms and related words (henceforth referred to as "A"), and unrelated and related words ("N"), including Group as a between-participants factor. Difference waves were used to factor out inherent differences between the two groups. Note that, in the following analysis, we only report interactions with and effects of Group for the sake of brevity. Furthermore, the additional analysis was only conducted for the N400 time window, as the presence or absence of a late positivity was the criterion for the group split (thus rendering the comparison trivial).

Group Split (N400 Time Window: 270–470 msec)

In the N400 time window, the statistical analysis revealed an ROI × Type × Group interaction, $F(3,45) = 3.47$, $p < .04$. Separate analyses within each ROI showed a significant Type × Group interaction only in the left posterior region, $F(1,15) = 6.07$, $p < .027$. This interaction was resolved by Type in order to examine whether the two groups would indeed differ for the A contrast but not for the N contrast. As predicted, there was a significant effect of Group for A, $F(1,15) = 4.82$, $p < .045$, but not for N ($p > .29$).

This critical difference between the groups with respect to the A contrast was further supported by the analysis of the midline electrodes. Here, the interaction Electrode × Type × Group was marginally significant, $F(3,45) = 2.55$, $p < .09$. Analyses for each electrode showed that the interaction Type × Group was marginal at CZ, $F(1,15) = 4.14$, $p < .06$, and significant at PZ, $F(1,15) = 5.91$, $p < .03$, and OZ, $F(1,15) = 6.73$, $p < .025$. In all cases, the A contrast yielded significant Group differences, CZ: $F(1,15) = 5.03$, $p < .041$; PZ: $F(1,15) = 7.90$, $p < .02$; OZ: $F(1,15) = 22.74$, $p < .01$, whereas there were no effects of Group for the N contrast (all Fs < 1).

The results of the group split thus suggest that there is a correlation between the early positivity effect for the antonyms and the late positivities for the nonantonym conditions: only the group of participants who were selected for showing late positivity effects also showed the early effect. By contrast, the relative effect between the related and unrelated conditions did not differ between the two groups. If, as suggested above, this overall pattern results from strategic differences between the two groups—with the "positivity group" behaving similarly to the participants in Experiment 1 and the "nonpositivity group" behaving similarly to the participants in

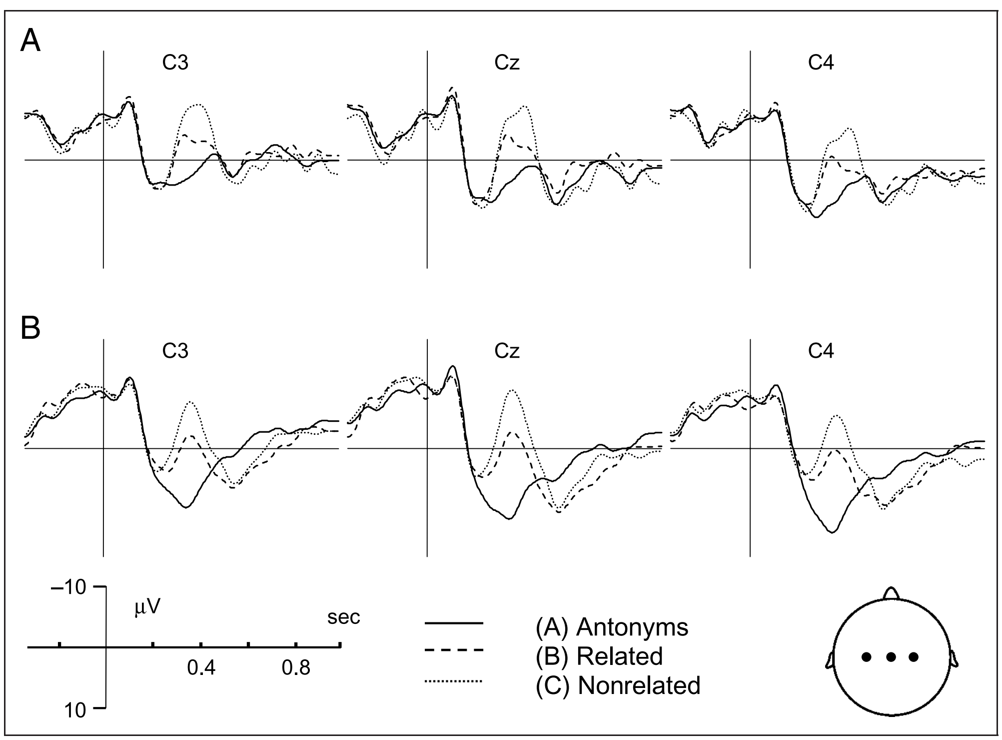


Figure 5. Two groups of grand averaged ERPs for antonyms and related and unrelated conditions in Experiment 3 (onset at the vertical bar). (A) Grand averaged ERPs for subjects ($n = 9$) who showed no late positivity. (B) Grand averaged ERPs for subjects ($n = 8$) who clearly showed a late positivity. The results revealed that subjects who showed a late positivity also showed an early positive peak for antonyms. Negativity is plotted upward.

Experiment 2—we should expect to see very similar effects in a direct comparison of our first two experiments. Thus, we should expect to find (a) a difference between the relative effect for the antonym versus the related condition (A) in the N400 time window, (b) a corresponding difference in the late positivity time window, and (c) no difference across experiments for the N400 contrast between related and unrelated stimuli (N).

Comparison of Experiments 1 and 2

N400 Time Window

Difference waves for the N400 were calculated as for the group split in Experiment 3 (A = ANT − REL; N = NON − REL). In the N400 time window, the statistical analysis revealed an ROI × Type × Group interaction, $F(3,96) = 8.40$, $p < .002$. Separate analyses within each ROI showed a significant Type × Group interaction only in the posterior regions: left posterior: $F(1,32) = 18.38$, $p < .0001$; right posterior: $F(1,32) = 23.90$, $p < .0001$. The interactions were resolved by Type, in order to examine whether the two groups would indeed differ for the A contrast but not for the N contrast. As predicted, there was a significant effect of Group for A, left posterior: $F(1,16) = 11.11$, $p < .003$; right posterior: $F(1,16) = 19.59$, $p < .0001$, but not for N (left posterior: $p > .24$; right posterior: $p > .07$).

This critical difference between the groups with respect to the A contrast was further supported by the analysis of the midline electrodes. As for the lateral electrodes, the interaction Electrode × Type × Group was significant, $F(3,96) = 5.57$, $p < .015$. Analyses for each electrode showed that the interaction Type × Group was significant at CZ, $F(1,32) = 7.13$, $p < .018$, PZ, $F(1,32) = 20.49$, $p < .0001$, and OZ, $F(1,32) = 36.59$, $p < .0001$. In all cases, the A contrast yielded significant Group differences, CZ: $F(1,16) = 6.36$, $p < .018$; PZ: $F(1,16) = 21.21$, $p < .0001$; OZ: $F(1,16) = 26.43$, $p < .0001$, whereas there were no effects of Group for the N contrast (CZ: $F < 1$; PZ: $p > .18$; OZ: $p > .08$).

Late Positivity

Difference waves for the P600 time window were calculated between related words and antonyms (A = REL − ANT), and unrelated words and antonyms (U = NON − ANT). In the P600 time window, the statistical analysis revealed an ROI × Type × Group interaction, $F(3,96) = 9.33$, $p < .0001$. Separate analyses within each ROI showed a significant Type × Group interaction only in the left posterior region, $F(1,32) = 10.12$, $p < .005$. The interaction was resolved by Type, in order to examine whether the two groups would indeed differ for the A contrast as well as for the U contrast. As predicted, there was a significant effect of Group for A, $F(1,16) = 11.37$, $p < .003$, and U, $F(1,16) = 36.71$, $p < .0001$.

The direct comparison of Experiments 1 and 2 showed that, in the N400 time window, the A contrast differed between experiments, whereas the N contrast did not. In the late positivity time window, there were corresponding differences between the A and the U contrasts between the two studies. The contrast between Experiments 1 and 2 is thus fully equivalent to the difference between the two groups in Experiment 3 (see Figure 6).

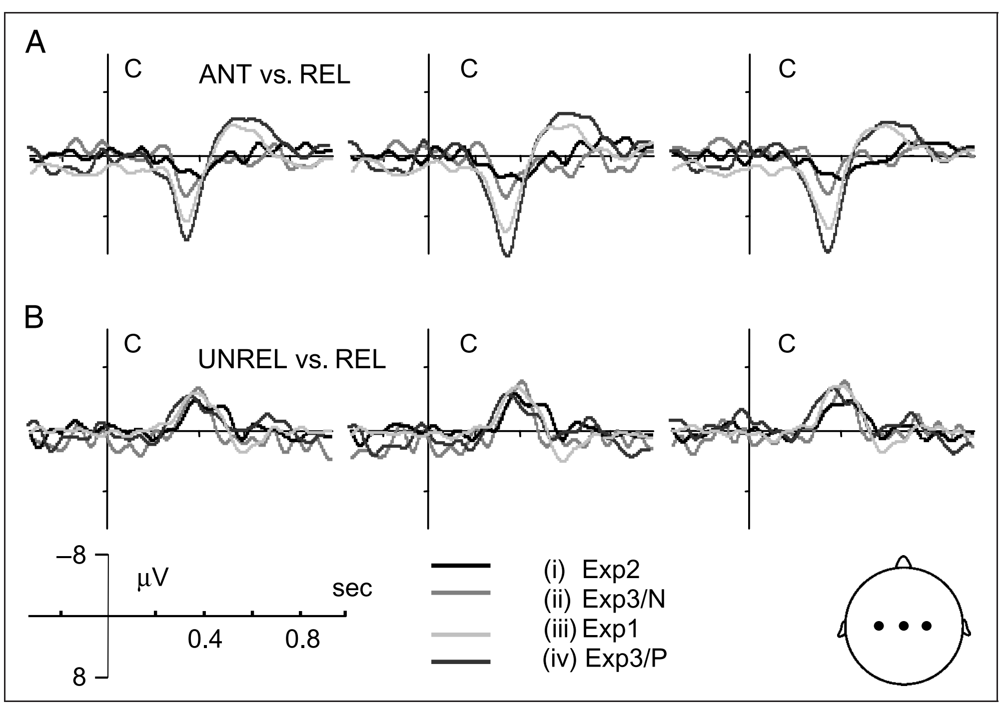


Figure 6. Comparison of difference waves for Experiments 1 and 2 and for the two subgroups of Experiment 3 (Exp3/P = positivity group; Exp3/N = nonpositivity group). (A) Difference waves for antonyms versus related conditions showed an early as well as a late positivity for Experiment 1 and the positivity group of Experiment 3 in comparison to Experiment 2 and the nonpositivity group of Experiment 3. The small positive dip for the latter two experiments is due to an additional semantic priming effect for antonyms relative to related conditions and thus reflects a decreased N400. (B) Difference waves for unrelated versus related conditions showed no difference between experiments and/or groups. Negativity is plotted upward.

Taken together, these findings provide strong converging support for the assumption that the N400 effect in Experiment 1 indeed results from the superposition of two distinct components: an N400 and a P300. Whereas the N400 reduction between the critical stimulus types remains unaffected by the experimental context (as shown by the absence of a group effect for the N contrast in the N400 time window; see Figure 6B), the ''embedded positivity'' for the antonyms is modulated by task requirements and strategic factors (see Figure 6A).

DISCUSSION

We have presented three ERP experiments examining the interplay between the N400 and the P300 in the processing of relational semantic information. Experiment 1 compared electrophysiological responses to antonym relations, semantically related words, and unrelated words in a sentence context and using a sensicality judgment task, whereas Experiments 2 and 3 presented the critical stimuli as word pairs. In Experiment 2, the critical conditions were rendered irrelevant to the task by including further stimulus pairs with a pseudoword in first or second position and using a lexical decision task. By contrast, Experiment 3 required participants to perform an antonymy judgment task. In all three experimental environments, the critical stimuli engendered a graded N400 response of the following form: unrelated words > related words > antonyms. In addition, we observed several positivities that were modulated by the experimental context: in Experiment 1 and in a subgroup of participants in Experiment 3, the antonym condition elicited a positive deflection in the N400 time window and the two nonantonym conditions engendered a late positivity. We hypothesized that the group differences in Experiment 3 may have been due to differences in individual processing strategy, with several participants adopting a strategy analogous to that in Experiment 1 and others performing as in Experiment 2. Converging support for this assumption stems from the direct comparison of the first two experiments, which revealed a cross-experimental difference for the contrast between antonyms and related words in the N400 time window, but no such difference for the contrast between related and unrelated words in the same time window. Corresponding cross-experimental differences were observed with respect to the late positivities for the nonantonym conditions. Thus, the group split in Experiment 3 indeed revealed the identical pattern to the comparison between Experiments 1 and 2.

Semantic Association: Context-independent N400 Differences

In combination, the three experiments show that the effects of semantic relatedness within the N400 are independent of the experimental environment in which the critical stimuli are presented. This finding is in line with a large number of previous results indicating that N400 effects of semantic association can be evoked without a task focusing on relatedness and even via unattended stimuli (e.g., Nunez-Pena & Honrubia-Serrano, 2005; Perrin & Garcia-Larrea, 2003; Rolke, Heil, Streb, & Hennighausen, 2001; Kutas & Federmeier, 2000; Kutas & Hillyard, 1984). It therefore appears that a word's associations within a semantic network are activated automatically whenever that word is processed, irrespective of task and experimental context. We were able to show this directly for the unrelated versus related word pairs by means of the interexperimental comparison between Experiments 1 and 2, which revealed a highly comparable difference between the two conditions in the two studies. For the comparison between antonyms versus related word pairs, the same argument can be made implicitly, because both Experiments 1 and 2 showed a significant difference between these two conditions within the N400 time window, although the size of this difference varied between the experiments.

As a final remark on the N400 effects in the present experiments, it is interesting that there appears to be no inherent advantage for the processing of real words as opposed to pseudowords with respect to the processing effort reflected by the N400 component. Recall that the N400 effect for the pseudowords was indistinguishable from that for the unrelated words in Experiment 2, thus indicating that there is no categorical difference between the two types of stimuli. This appears plausible in view of the fact that the transition between real words and pseudowords is not completely sharp: very low frequency words (e.g., *oologist*, an expert on birds' eggs) might well be classified as pseudowords under a number of circumstances. Conversely, pseudowords can be endowed with a meaning relatively effortlessly given a particular context (cf. the conceptual associations evoked by Lewis Carroll's *Jabberwocky*).

Prediction, Experimental Environment, and Processing Strategy: Experiment-specific Positivity Effects

More importantly, for the purposes of the present article, our experiments showed an early positive response to the antonyms (within the N400 time window and augmenting the overall N400 reduction) in Experiment 1 and in a subgroup of the participants of Experiment 3. In contrast to the effects of semantic relatedness, which did not differ across the three experiments (see the previous section), the early positivity was crucially modulated as a function of the experimental environment (task and mode of stimulus presentation).

For the antonym condition in Experiment 1, the task-relevant last word of the sentence fulfills the clear and unambiguous expectation set up by the sentence context

(*The opposite of black is* . . .). It therefore elicits a target-related P300 effect, which occurs in the same time range as the N400 because the correct identification of the predicted word (antonym) does not require a lexical search (there is a unique prediction that may either be fulfilled or not). By contrast, no early positivity was observed when the antonym relation was task irrelevant (Experiment 2). This difference between the two studies was confirmed by the direct statistical comparison.[1]

The results of Experiment 3 further suggest that modulations of P300 effects within the N400 time window may even go beyond simple task effects. In this study, half of the participants showed exactly the same component pattern as that observed in Experiment 1, whereas the other half showed an analogous ERP response to that in Experiment 2. This descriptive assumption was supported by the statistical comparison of the two groups, which yielded identical results to the direct comparison between Experiments 1 and 2. These findings suggest that interindividual differences in processing strategy may have a significant impact upon the neurophysiological patterns observed.

With respect to the source of the strategic differences between the two participant groups in Experiment 3, we can only speculate. Neither could the group split be traced back to any systematic parameter nor were there significant differences in the behavioral performance of the two groups. There was, however, a numerical trend toward faster reaction times (in the range of approximately 90 msec) for the positivity group ($M = 425.89$ msec, $SD = 91.96$ sec; nonpositivity group: $M = 516.59$ sec, $SD = 181.04$ sec), although this group difference did not reach significance. Nonetheless, it appears plausible to assume that, by adopting a strategy analogous to that forced upon the processing system by a constraining sentence context, the positivity group may have been able to perform the task more effectively. Perhaps a behavioral advantage would indeed have been brought out more clearly by a more demanding task or by time pressure.

Consequences for the Interpretation of ERP Differences within the N400 Time Window

The comparison of the three experiments presented here revealed that functionally distinct ERP components may be superimposed within the N400 time window. This constellation yields what appears to be an ''N400 difference'' on the surface, whereas, in fact, requiring a more complex explanation. The present findings thus go beyond previous discussions in the literature that were concerned with the effects of possible P300 latency shifts and their consequences for the interpretation of ERP differences within the N400 time window. Rather, they show additivity between a ''true'' N400 effect and a task- or strategy-related P300 effect within this time range.

As an example of the consequences of this result for the interpretation of what appear to be N400 reductions, recall the results of the experiment by Kutas and Iragui (1998), which were already discussed in the Introduction. Having shown that the comparison between antonyms and unrelated word pairs engenders an ERP difference that results from the superposition of two effects (an N400 reduction due to semantic relatedness and a P300 augmentation due to the experimental environment), it is no longer possible to provide a clear-cut interpretation of the age-related reduction of the electrophysiological difference between these stimulus types. Thus, the changes observed as a function of age may result either from a reduction of the N400 proper, from a reduction of the P300 effect, or from a reduction of both.

More generally, these observations indicate that the results of ERP studies on language processing require a much more detailed screening for possible task- or strategy-related positivity effects than previously assumed. Notably, this issue goes beyond the question of whether late language-related positivities should be regarded as P300s (e.g., Frisch, Kotz, von Cramon, & Friederici, 2003; Osterhout & Hagoort, 1999; Coulson et al., 1998), but rather concerns the possible occurrence of P300 effects within the N400 time range. As shown in the present studies, these effects may be relatively difficult to detect because of component overlap. Nonetheless, they clearly cannot be neglected because surface ERP differences call for a fundamentally different interpretation in their presence. Crucially, the occurrence of ''embedded P300s'' is not only restricted to the lexical–semantic domain as illustrated in the present article, but can also be observed in syntactic manipulations at the sentence level. A case in point is provided by experiments on the reanalysis of subject–object ambiguities in German. Within this domain, several studies have reported early positive effects for a (dispreferred) disambiguation toward an object-first order at the clause-final position (Friederici, Steinhauer, Mecklinger, & Meyer, 1998; Mecklinger, Schriefers, Steinhauer, & Friederici, 1995). Strikingly, this positivity has also been observed at the clause-final auxiliary (which completes the proposition expressed by the sentence) even when word order disambiguation was effected at an earlier point in the sentence (see Friederici et al., 1998; Figure 4). This finding suggests that the early positivity may not be a correlate of grammatical function reanalysis per se, but that it may rather be related to the experimental task demands. In the studies in question, participants performed a comprehension task, which always focused upon the object of the critical experimental sentences, hence leading to a target effect at the element completing the proposition in the object-first sentences. Converging support for an interpretation along these lines stems from a recent ERP study examining the processing of similar ambiguities under different task requirements (comprehension question vs. binary acceptability judgment) (Gaermer, Schlesewsky, Roehm, Friederici, & Bornkessel-Schlesewsky, submitted). Gaermer et al. (submitted) observed a P300 modulation at the sentence-final auxiliary, which occurred as a function of task demands and was measurable even in subject-initial sentences. It therefore appears highly plausible that the overlap between P300 effects in the N400 time window and language-related ERP effects is not restricted to the lexical–semantic domain, but that it rather constitutes a more general phenomenon in experiments on sentence processing.

Conclusion

The present experiments revealed that the extreme N400 reduction observable in highly predictable lexical–semantic settings (antonym relations) results from the superposition of two independent ERP effects: a reduced N400 due to semantic relatedness, and an increased P300 due to target predictability. Moreover, the P300 effects observed were not only attributable to concrete task demands, but were also influenced by the individual processing strategies used to achieve successful task performance. The finding that P300 effects can occur in parallel with functionally distinct effects in ERP studies on language comprehension calls for a more cautious interpretation of language-related ERP differences.

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Note

1. A similar explanation applies for the positivity observed in response to the pseudowords in Experiment 2. Similarly to the antonyms in Experiment 1, these are also target stimuli because of the lexical decision task. However, to be correctly identified as such, they require a lexical search, which is reflected in the increased N400 in comparison to related words and antonyms. Therefore, the P300 is delayed to the post-N400 time range, a finding that has been observed in a number of experiments examining the processing of pseudowords (e.g., Bentin, Mouchetant-Rostaing, Giard, Echallier, & Pernier, 1999; Bentin et al., 1985). In this way, the early positivity for antonyms and the late positivity for pseudowords appear to be amenable to a very similar functional interpretation: both of these stimulus types are overtly predicted because they are targets in the context of the experimental task. They differ only with respect to the processes that are prerequisites for target identification, hence leading to differences in P300 latency.

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