Event-related Potential Correlates of Negation in a Sentence–Picture Verification Paradigm

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Abstract

■ In a sentence–picture verification paradigm, participants were presented in a rapid-serial-visual-presentation paradigm with affirmative or negative sentences (e.g., "In the front of the tower there is a/no ghost") followed by a matching or mismatching picture. Response latencies and event-related potentials (ERPs) were measured during reading and verification. An enhanced negative shift in the ERPs for the subject noun (i.e., "ghost") in negative, compared to affirmative sentences, was found during reading. We relate this ERP deflection to enhanced processing demands required by the negative particle *no*. Although this effect suggests a direct impact of negation on language processing, results for picture processing reveal that negation is not immediately integrated into sentence meaning. When the delay of picture presentation was short (250 msec), verification latencies and ERPs evoked by the picture showed a priming effect independent of whether the sentence contained a negation. Unprimed pictures (foreground object not mentioned in the sentence) led to longer latencies and higher N400 amplitudes than primed pictures (foreground object mentioned in the sentence). Main effects of negation showed up only in a late positive-going ERP effect. In contrast, when the delay was long (1500 msec), we observed main effects of truth value and negation in addition to the priming effect already in the N400 time window, that is, negation is fully integrated into sentence meaning only at a later point in the comprehension process. When negation has not yet been integrated, verification decisions appear to be modulated by additional time-consuming reanalysis processes. ■

INTRODUCTION

Albert Einstein once said "I have no special talents." Usually, a short sentence such as this is not particularly hard to understand, even though it contains a negation. Negation is a linguistic operator that takes a whole proposition into its scope (in the example above, the proposition that the speaker has special talents). It thereby constitutes a means to communicating that the state of affairs denoted by this proposition (called the negated state of affairs) does not hold for the situation under consideration. Depending on the linguistic and situational context, and/or the world knowledge of the listener, an actual state of affairs may be inferred (in the example above, e.g., the fact that the speaker is highly talented in several respects; cf. Kaup, Zwaan, & Lüdtke, 2007). Research has shown longer processing times and higher error rates for negative compared to affirmative sentences (for overviews, see Kaup, Zwaan, et al., 2007; Lüdtke & Kaup, 2006; Carpenter & Just, 1975; Clark, 1974). Similarly, higher cortical activation during the comprehension of negative compared to affirmative sentences has been observed using brain imaging (Carpenter, Just, Keller, Eddy, & Thulborn, 1999). However, exactly what kind of additional processing is required by negative sentences is still a matter of debate.

Comprehension of negated sentences is differently modeled by propositional theories and simulation accounts of cognitive processing. According to propositional theories, the higher processing demand comes about because a negative tag has to be incorporated into the meaning representation of the sentence, resulting in an additional level of propositional encapsulation (Carpenter & Just, 1975; Clark & Chase, 1972). According to the *two-step simulation hypothesis* of negation processing (e.g., Kaup, Lüdtke, & Zwaan, 2006; Kaup & Zwaan, 2003), the higher processing demand reflects that the comprehender is creating two simulations when processing a negative sentence: a simulation of the negated state of affairs and a simulation of the actual state of affairs. This hypothesis is based on the view that comprehension is tantamount to mentally simulating the states of affairs described in the linguistic input (Fischer & Zwaan, in press; Glenberg & Kaschak, 2002; Barsalou, 1999; Glenberg, 1997). When processing a sentence such as "The door is not closed," the comprehender presumably simulates a closed as well as an open door. Negation is implicitly encoded in the deviation between both simulations.

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With regard to temporal characteristics of the comprehension process, propositional theories are relatively mute. It is not stated explicitly whether the comprehender in a first step represents the encapsulated proposition and then applies the negation operator to it, or whether the complex negated proposition is created right away. In contrast, the two-step simulation hypothesis explicitly assumes that the comprehender first simulates the negated state of affairs and only at a later point in the comprehension process turns attention onto the simulation of the actual state of affairs. Negation presumably is being integrated into the meaning representation, once the comprehender is turning attention away from the simulation of the negated state of affairs and onto the simulation of the actual state of affairs. Thus, according to the two-step simulation hypothesis, negation is incorporated into the meaning representation at a rather late stage in the comprehension process.

Indeed, the results of a number of behavioral studies indicate that negation is not incorporated into the representation of the sentence meaning right away, but only at a rather late stage in the comprehension process. For instance, the processing of a picture of an open door is facilitated relative to a picture of a closed door only after about 1000 msec after reading the sentence ''The door is not closed.'' This indicates that it takes comprehenders about 1000 msec to integrate the negation into the representation of the sentence meaning, or—in terms of the two-step simulation hypothesis—to shift attention away from the negated and onto the actual state of affairs (Kaup et al., 2006; see also Kaup, Yaxley, Madden, Zwaan, & Lüdtke, 2007; Kaup, Zwaan, et al., 2007; Hasson & Glucksberg, 2006; Kaup, Lüdtke, & Zwaan, 2005; Giora, Balaban, Fein, & Alkabets, 2004).

Interestingly, a number of event-related potential (ERP) studies employing a sentence verification paradigm also indicate that negation is initially not integrated into the representation of the sentence meaning. In these studies, participants read and verified true or false affirmative and negative sentences [e.g., (1)–(4)], and ERPs were recorded for the sentence-final words (Hald, Kutas, Urbach, & Pahrhizkari, 2004; Kounios & Holcomb, 1992; Katayama, Miyata, & Yagi, 1987; Fischler, Bloom, Childers, Roucos, & Perry, 1983).

(1) A robin is a bird. (True Aff)

(2) A robin is not a bird. (False Neg)

(3) A robin is a tree. (False Aff)

(4) A robin is not a tree. (True Neg)

In all studies, for the affirmative as well as for the negative conditions, the amplitude of the N400, a negative-going waveform peaking at 400 msec, was smaller when the final word of the sentence had a semantic relation to the word in grammatical subject position [(1) and (2)] than when this was not the case [(3) and (4); Fischler et al., 1983; see also Kounios & Holcomb, 1992; Katayama et al., 1987]. The same effect was found when subject and final word had a relation according to general world knowledge [as in (5); Hald et al., 2004].

(5) Hawai is / is not tropical / cold.

From language-related ERP research, the N400 amplitude is known to be larger to words that are semantically unrelated (vs. related) with preceding words (e.g., Bentin, McCarthy, & Wood, 1985), with sentence contexts (e.g., Kutas & Hillyard, 1980), with global discourse contexts (e.g., Nieuwland & Van Berkum, 2006), or when there is no (vs. is) relationship between words on the basis of general world knowledge (Hagoort, Hald, Bastiaansen, & Petersson, 2004). Enhanced N400 amplitudes in the ERP are usually interpreted as reflecting a hampered semantic integration process during language comprehension (for a review, see Kutas & Federmeier, 2000). This seems to suggest that the N400 effect observed in the studies reported above reflects a semantic integration mechanism that does not take negation into account. In other words, N400 amplitudes for the sentence-final word are enhanced in conditions in which this word is not primed (vs. primed) by the word in the grammatical subject position, independent of negation. From the perspective of the two-step simulation hypothesis, this priming effect is not surprising, but presumably reflects that comprehenders at the time of measurement are still engaged in the first simulation process, which is the same for affirmative (e.g., ''Hawai is cold'') and negative sentences (e.g., ''Hawai is not cold''). Because comprehenders have not yet integrated the negation into the meaning representation, negation does not influence the N400 amplitudes.

Regarding the proposed later integration of negation, former ERP studies are not conclusive. Despite the fact that negation did not have any direct influences on the N400 amplitudes, participants' verification accuracies in these studies were clearly above chance. This tells us that comprehenders *did* take the negation into account when verifying the sentences. Given the assumed lag with which negation is being integrated into the meaning representation of the sentence, it seems plausible that negation modulates sentence processing and verification relatively late in this paradigm, possibly not until shortly before response preparation. In line with this assumption, Fischler et al. (1983) reported a virtually greater positivity in the ERPs elicited by the sentence-final words in negative sentences compared to affirmative ones about 800–1120 msec after word onset, which failed to reach significance. Also in the other sentence verification studies with English materials, no direct ERP effects of negation were being reported (Hald et al., 2004; Kounios & Holcomb, 1992), and the results of a

Japanese study by Katayama et al. (1987) are difficult to interpret. Word order in Japanese is subject–object–verb (e.g., ''Robin bird is/is not'' [literal translation][1]). Thus, it was the final verb phrase that decided whether the sentence was affirmative or negative. Higher amplitudes of the P3 component to affirmative than to negative verb phrases were observed. However, this may reflect higher frequency of usage of the affirmative verb phrase rather than semantic differences between affirmative and negative sentences.

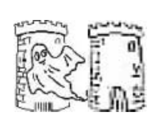
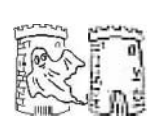
Taken together, former ERP studies with negated sentences basically revealed N400 priming effects. There were no conclusive neuronal indications that negation is incorporated into sentence meaning. The fact that in previous ERP studies the sentence-final word determined whether the sentence is true or false makes the interpretation extra difficult because sentence verification processes and sentence wrap-up effects (cf. Hagoort, 2003; Osterhout, 1997) cannot be disentangled.

Aims of the Current Study

The present study was set out to characterize neuronal processing of negation using a sentence–picture verification paradigm. Participants read sentences such as ''In front of the X there is a/no Y'' and afterward viewed a picture that either depicted a Y in front of the X or another object in front of the X (for details, see Table 1). In contrast to the ERP studies reported above, verification is temporally distinct from sentence comprehension in the present paradigm. Participants first read the sentence that in itself is neither true nor false. Only when they later view the picture can they start the verification process. This allowed us to manipulate the amount of time that participants have available for comprehending prior to verification. Accordingly, to obtain more information regarding the time course of negation processing, we presented the picture with two delays, either 250 or 1500 msec after sentence reading.

In line with previous ERP research showing that pictures as well as words can elicit N400 components (Ganis, Kutas, & Serano, 1996; Nigam, Hoffman, & Simons, 1992), we expect to observe N400 effects in the ERPs elicited by the picture. Similar to previous ERP studies, we should observe a negation-by-truth value interaction: N400 amplitudes should be relatively low in conditions in which the picture is *primed* by the sentence. This should be the case for the true affirmative and the false negative condition (cf. Table 1). In contrast, N400 amplitudes should be relatively high in conditions in which the picture is not primed by the sentence. This is the case in the false affirmative and the true negative condition (cf. Table 1). It should be noted that this potential priming effect may have at least two sources. First, amplitudes may be relatively low in the primed conditions simply because the depicted foreground object was mentioned in the sentence. Second, amplitudes may be low in these conditions because, according to the two-step simulation hypothesis, the comprehender has simulated the depicted state of affairs when processing the sentence: For affirmative sentences, the depicted state of affairs in these conditions corresponds to the described state of affairs. In the negative conditions, it corresponds to the negated state of affairs, which presumably is being simulated first during sentence processing (see above). In principle, these priming effects should be observed at both delay conditions because (a) *mentioning* should facilitate picture processing even after a certain delay, and (b) because the comprehender in both delay conditions has simulated the depicted state of affairs in the primed but not in the unprimed conditions. However, priming effects

Table 1. Sample Materials

Sentence	*Picture*	*Relation*	*Simulations*	*Condition*	*Priming*
In front of the tower there is a ghost.		Mentioned		True affirmative	Primed
In front of the tower there is a ghost.		Not mentioned		False affirmative	Not primed
In front of the tower there is no ghost.		Not mentioned		True negative	Not primed
In front of the tower there is no ghost.		Mentioned		False negative	Primed

may be slightly attenuated in the long delay condition because (a) the effect of a surface-level variable such as mentioning may decline over time, and (b) the simulation that corresponds to the depicted state of affairs may no longer be in the comprehender's focus of attention, as he or she may have already shifted toward the simulation of the actual state of affairs (e.g., a tower with nothing in front).[2]

More important to the goals of our study, we expect to find a main effect of negation in the ERPs elicited by the picture. Considering that integration of negation takes a substantial amount of time (see above), we predict that negation will affect the ERPs differently for the two delay conditions. In the short-delay condition, we expect that comprehenders have not yet integrated the negation into the representation of the sentence meaning before picture presentation. Accordingly, in order to solve the verification task, comprehenders must make up for the integration when the picture comes up. This can be expected to be rather time consuming. ERP effects of negation are therefore probably associated with the planning of the appropriate response to the verification task. In order to track those response preparation effects, special attention will be paid to late time windows in the ERPs elicited by the picture. In contrast, in the long-delay condition, comprehenders had enough time (1500 msec) to incorporate the negation into the meaning representation, before being presented with the picture. Accordingly, they have available a more complex representation in the negative than in the affirmative versions when the picture comes up. This complexity difference should be reflected in the ERPs elicited by the picture, but this time in relatively early time windows. Thus, in the long-delay condition, we predict that negation effects will occur in earlier time windows than in the short-delay condition.

Parallel to the ERPs evoked by the picture, we will also collect response times in the verification task. Response time patterns should resemble the ERP effects. Therefore, we expect to find faster response times in the primed than in the unprimed conditions at both delays, with the possibility that the resulting negation-by-truth value interaction effects are smaller in the long than in the short-delay condition. Similarly, for the main effect of negation, we expect to find effects in both delay conditions but for different reasons as described above. In the short delay condition, verification times for negative conditions should be prolonged compared to affirmative conditions because of the time-consuming retroactive integration process. In the long delay condition, the successful integration of negation before picture presentation leads to a more complex representation compared to affirmative versions, which may also be reflected in extended response times. However, it is possible that the main effect of negation in the long delay may be smaller than the one in the short delay.

As a third goal of the present study, we will investigate effects of negation immediately after the negation marker is being encountered during sentence comprehension. Our sentence–picture verification paradigm will allow us to observe effects of negation in the electroencephalogram (EEG) *during* sentence comprehension, independent of any priming or verification processes. In contrast to the reported ERP studies, the sentences we used are, by themselves, neither true nor false (see above). Affirmative and negative versions of a sentence only differ with respect to whether the penultimate word of the sentence is an "ein" ("a") or a "kein" ("no"). Hence, the strength of the semantic association between subject and object is identical between conditions. This allows us to explore the neurocognitive processing of the final word of the sentence as a function of negation. As of yet there are, to the best of our knowledge, no studies that analyzed ERPs evoked by affirmed or negated nouns within sentence comprehension independent of priming and potential verification processes. Thus, no clearcut predictions can be made regarding the differences in the ERPs evoked by affirmed or negated subject nouns. However, it should be noted that potential negation effects that show up immediately after processing of the negation marker would not be inconsistent with our hypothesis of a delayed integration of negation into the meaning representation of the sentence. According to the two-step simulation hypothesis, the reader first simulates the negated state of affairs, but in doing so, he or she of course has to keep in mind that the sentence was negative and that the simulated state of affairs does not correspond to the actual state of affairs. Thus, at the very least, negative sentences should lead to an additional memory load once the negation marker has been encountered in the sentence.

To summarize, in this study we are interested in ERP correlates of negation, both *during*, as well as *after* sentence reading. During sentence reading, we are interested in the effects of negation on the processing of the noun that follows the negation marker in the sentence. After sentence reading, we are interested in the processes by which negation is being integrated into the sentence meaning. Thus, the main focus of the present study is not on syntactic but on semantic effects of negation.

METHODS

Participants

Participants were 17 undergraduate students from the University of Konstanz (9 women, 8 men), all native speakers of German with no discernible uncorrected deficits in hearing or vision. They were paid for their participation. Only right-handed subjects were included, as ascertained by the Edinburg Handedness Questionnaire (Oldfield, 1971). No participant had a neurological history. The data for one student were excluded because of technical problems during the experimental session.

Stimuli

Eighty experimental sentences were constructed. These were of the form ''Vor/Auf dem X ist ein/kein Y'' (''In front of/On top of the X there is a/no Y''), with the surface structures of the two versions of a sentence only differing with respect to the penultimate word that either affirmed or negated the noun in the subject position (i.e., Y) [e.g., ''Vor dem Turm ist ein Geist'' (''In front of the tower there is a ghost'')/''Vor dem Turm ist kein Geist'' (''In front of the tower there is no ghost'')]. For the 80 experimental sentences, 11 different monosyllabic background objects (i.e., X) were used [e.g., ''Turm'' (''tower'') or ''Tisch'' (''table'')]. Every background object was used seven or eight times. For the 80 experimental sentences, 80 different disyllabic subject nouns were used. Only nouns with masculine or neuter gender were used so that the article was ''ein'' (''a'') or ''kein'' (''no'') for all sentences.

In addition, 80 black-and-white pictures (black graphics on a white screen) were constructed, each of which depicted the situation described in the affirmative version of one of the experimental sentences. All pictures were such that the two objects could be easily identified, and each was scaled to a size of 200 by 150 pixels. Each experimental sentence was paired with two pictures, one depicting the situation described in the affirmative version (e.g., a picture of a ghost in front of a tower for ''In front of the tower there is a/no ghost''), and the other depicting a different object in front of the same background object (e.g., a picture of a lion in front of a tower). The combination of one sentence and two pictures yielded four conditions for each item: true affirmative, false affirmative, true negative, and false negative, with the predicted priming being present in the true affirmative and the false negative condition but not in the false affirmative or the true negative condition. The correct responses in the verification task depended on the version: True versions required a ''true'' response; false versions a ''false'' response. For 40 of the items, the delay between sentence and picture was 250 msec, for the remaining 40 items it was 1500 msec. Word length and frequency were balanced for the two delay conditions using an on-line dictionary of German (www.wortschatz.uni-leipzig.de).

Each participant saw all four versions of each of the 80 items, resulting in 320 trials. Of these, 160 contained affirmative and 160 negative sentences. Eighty of each of these were followed by a matching picture and 80 by a mismatching picture (with 40 in the short- and 40 in the long-delay condition). The 320 trials were divided into six blocks including 56 (Blocks 1, 2, 4, and 5) or 48 items (Blocks 3 and 6). Each block included maximally one version of an experimental sentence, but a picture could be presented twice in a block. For one half of the trials in each block, the delay was short and for the other half long. Each block included an equivalent number of items in the four conditions. The 11 background objects were divided over all six blocks. Short breaks were between the blocks.

This produced a 2 (delay: short vs. long) × 2 (negation: affirmative vs. negative) × 2 (truth value: true vs. false) design, with repeated measurement on negation and truth value. Delay was manipulated within participants but between items. It should be noted that with this statistical design, the predicted priming effects are present in case a negation-by-truth-value interaction is being observed whereby the true affirmative and the false negative conditions should be associated with lower N400 amplitudes and response times than the false affirmative and true negative conditions.

Procedure

Participants sat in a sound-attenuated booth. The materials were displayed using the software Presentation (Neurobehavioral Systems, www.neurobs.com). Each trial began with a blank monitor for 2000 msec followed by a fixation point for 500 msec. Then the sentence was presented word-by-word in the center of the screen, with each word being presented for 300 msec followed by a blank screen for 300 msec. After the final word of the sentence, a fixation cross appeared for 250 or 1500 msec depending on the trial's particular delay condition. Finally, the picture was presented for 250 msec. Participants indicated as quickly and accurately as possible whether the picture was true of the sentence just read. Half the participants made ''true'' responses with their left thumb and ''false'' responses with their right thumb. For the remaining participants, response hands were reversed. Participants were not given feedback on their responses. After the picture disappeared, participants had a maximum of 4000 msec to react. If no response took place, the next trial started. Each test session started with a practice block of 24 trials, in which participants received feedback on their responses.

ERPs were recorded continuously from Ag/AgCl electrodes held in place on the scalp with an elastic cap (Electro-Cap, Germany). Scalp locations included 62 standard locations according to the 10–10 system (Chatrian, Lettich, & Nelson, 1988). Two additional electrodes were placed below both eyes. All electrodes were online referenced to Cz. Average reference was used for analysis of ERP data. All electrode impedances were less than 5 kΩ. EEG was recorded with a sampling rate of 250 Hz.

Data Analyses

Response latencies and ERPs were calculated for correct responses. Latencies and error rates of experimental trials were submitted to two 2 (delay) × 2 (negation) × 2 (truth value) analyses of variance (ANOVAs), with repeated measurement on all variables in the by-participants analyses but on only the latter two in the by-items analyses. One of these ANOVAs was based on participant variability (F_1), the other on item variability (F_2). In determining outliers, we employed a two-step procedure: First, the reaction times of each participant were converted to z scores. Then reaction times with a z score deviating more than 2 standard deviations from the mean z score of the respective item in the respective condition were discarded. This eliminated less than 3.8% of the data.

For the ERPs we used multiple source eye correction (MSEC; Berg & Scherg, 1994). Prior to the experiment, 80 calibration eye movements (vertical and horizontal) and 20 eye blinks were recorded from each participant. Using BESA (Brain Electrical Source Analysis; Megis Software GmbH), eye movements and blinks were averaged and subjected to a principal components analysis (PCA). Then characteristic scalp topographies for artifacts were separated from the continuous EEG.

The ERPs elicited during sentence reading by the penultimate word and the sentence subject word were analyzed in a combined time window. For this EEG analysis, trials were averaged off-line with an epoch of −200 msec before the onset of "ein"/"kein" ("a"/"no") up to 2000 msec thereafter. To explore spatio-temporal dynamics of negation processing within the sentences, 50-msec time-step analyses were performed with two types of ANOVAs, one including the factors negation ("ein" + subject noun vs. "kein" + subject noun) and region (anterior vs. posterior electrode positions), the other including the factors negation and hemisphere (left vs. right electrode positions). Electrode positions were summarized in regions of interest (ROIs), the anterior and the posterior ROI both included homologue electrode positions from both hemispheres and midline electrodes, together 22 electrode positions for each ROI (anterior: FP1, FP2, AF7, AF3, AF4, AF8, F5, F1, F2, F6, FT7, FC1, FC5, FC3, FC2, FC4, FC6, FT8, Fpz, AFz, Fz, FCz; posterior: TP7, CP5, CP3, CP1, CP2, CP4, CP6, TP8, P7, P1, P3, P4, P2, P8, PO9, PO1, PO2, PO10, O1, O2, Pz, Oz). The left and right ROI both included 23 electrode position (without midline electrode positions) (left: FP1, AF7, AF3, F5, F1, FT7, FC1, FC5, FC3, T7, C3, C5, TP7, CP5, CP3, CP1, P7, P1, P3, PO9, PO1, TP9, O1; right: FP2 AF4, AF8, F2, F6, C4, T8, C6, FC2, FC4, FC6, FT8, CP2, CP4, CP6, TP8, P4, P2, P8, PO2, PO10, FT10, O2). We only report effects that reach significance in three consecutive time windows.

For the analysis of the ERPs elicited by the picture, trials were averaged off-line with an epoch length of 1000 msec, including a prestimulus baseline from −200 to 0 msec with respect to the picture onset. To clarify temporal resolution of ERP effects in picture processing, 50-msec time-step ANOVAs were performed with the repeated measures factors delay (short vs. long), negation (affirmative vs. negative), truth value (true vs. false), and region (anterior electrode leads vs. posterior electrode leads). For the ERPs evoked by the picture, there were virtually no asymmetric effects. So we defined only an anterior and a posterior ROI as reported above. Fourway ANOVAs with the repeated measures factors delay, negation, truth value, and region were applied to ERP analysis. Time windows were determined with respect to results of 50-msec analyses, as well as with respect to previous works on language comprehension. Previously, contextual integration of visually presented images has been shown to elicit N400 effects. In accordance with other studies employing picture and word material (e.g., Federmeier & Kutas, 2001; Kutas & Federmeier, 2000), a time window of 250–550 msec was chosen for the analysis of N400 effects. In some of the studies that presented visual images, an earlier negativity, the N300 with a somewhat more frontal distribution, has been reported to overlap with the N400 (McPherson & Holcomb, 1999). To accomplish for possibly independent effects of picture processing in the N400 time window, we separated the analysis of the N400 into an early time window including a frontal N300 effect (250 msec–400 msec) and a later time window including a frontal negative shift in two conditions (short delay, true affirmative and false negative, 400–550 msec). For ERP analysis of the post N400 time slot, a time window of 550 to 1000 msec poststimulus onset was included in the

Table 2. Mean Latencies/Standard Deviations of Correct Responses (in msec), and Error Percentages (in parentheses) in the Sentence–Picture Verification Task

	Delay			
	Short		*Long*	
	Truth Value		*Truth Value*	
	True	*False*	*True*	*False*
Affirmative	676/128 (1.42)	817/237 (4.88)	660/163 (3.44)	761/253 (5.17)
Negative	961/234 (10.37)	877/212 (7.05)	812/229 (6.03)	766/219 (5.34)

analyses. For illustration purposes only, ERPs were low-pass filtered at 20 Hz.

RESULTS

Behavioral Data

Response Times in the Verification Task

The mean latencies, standard deviations, and the percentages of errors are displayed in Table 2. There was a main effect of negation [$F_1(1, 15) = 35.0, p < .001, F_2(1, 78) = 198.1, p < .001$], a main effect of truth value [$F_1(1, 15) = 4.6, p = .05, F_2(1, 78) = 9.0, p < .01$], and a main effect of delay [$F_1(1, 15) = 52.3, p < .001, F_2(1, 78) = 50.9, p < .001$]. As expected, there was also a Negation-by-Truth value interaction [$F_1(1, 15) = 22.8, p < .001, F_2(1, 78) = 80.9, p < .001$] and a Negation-by-Delay interaction [$F_1(1, 15) = 27.1, p < .001, F_2(1, 78) = 35.9, p < .001$], but no Delay-by-Truth value interaction (both $F < 1$). The interaction of delay, truth value, and negation was also significant [$F_1(1, 15) = 10.3, p < .01, F_2(1, 78) = 4.1, p < .05$].

Analyzing the data separately for the two delay conditions produced for the short delay a significant main effect of negation [$F_1(1, 15) = 60.2, p < .001, F_2(1, 39) = 223.9, p < .001$]. The main effect of truth value was only significant in the by-item analysis [$F_1(1, 15) = 3.8, p < .17, F_2(1, 39) = 5.2, p < .05$]. The Negation-by-Truth value interaction was significant in both analyses [$F_1(1, 15) = 25.6, p < .001, F_2(1, 39) = 54.9, p < .001$]. For the long delay there was also a significant main effect of negation [$F_1(1, 15) = 10.8, p < .01, F_2(1, 39) = 29.7, p < .001$] and a marginally significant main effect of truth value [$F_1(1, 15) = 3.3, p < .10, F_2(1, 39) = 4.4, p < .05$]. The Negation-by-Truth value interaction was also highly significant in this delay condition [$F_1(1, 15) = 16.3, p = .001, F_2(1, 39) = 31.8, p < .001$]. Separate analyses for the affirmative and negative sentences in the two delay conditions revealed for both delay conditions, as expected, that responses for affirmative sentences were shorter in the true than in the false condition [for both delay conditions: $F_1(1, 15) > 12, p < .01, F_2(1, 39) > 44, p < .001$], whereas those for negated sentences were shorter in the false than in the true condition [short delay: $F_1(1, 15) = 15.1, p < .01, F_2(1, 39) = 15.6, p < .001$; long delay: $F_1(1, 15) = 6.4, p < .05, F_2(1, 39) = 2.3, p < .15$]. Thus, as predicted, responses were shorter in those conditions in which the picture was presumably primed by the sentence, be it because the depicted foreground object was mentioned in the sentence, or because the comprehender had simulated the depicted state of affairs when the picture came up.

What does the three-way interaction of delay, negation, and truth value reflect? Two possible explanations arise from additional planned comparisons: First, for the false affirmative, the true negative, and the false negative versions, response times in the short-delay conditions were shorter than those in the long-delay conditions [for all comparisons: $F_1(1, 15) > 22.6, p < .001, t_2(1, 78) > 2.5, p < .02$]. In contrast, for the true affirmative, there was no difference between the delay conditions [$F_1(1, 15) = 1.5, p > .23, t_2(1.78) = 1.2, p > .20$]. Second, in both delay conditions, response times were shorter for affirmative than for negative versions [for all comparisons: $F_1(1, 15) > 3.9, p < .07, F_2(1, 39) > 19.8, p < .001$], except for the false versions in the long-delay condition. Here, negative and affirmative conditions did not differ (both Fs < 1).

Error Percentages in the Verification Task

In the overall 2 × 2 × 2 ANOVA, there was a main effect of negation [$F_1(1, 15) = 12.07, p < .01, F_2(1, 78) = 22.2, p < .001$] but no main effects of delay or truth value [delay: $F_1(1, 15) = 1.5, p > .22, F_2(1, 78) = 1.1, p > .28$; truth value: both $F < 1$]. The Negation-by-Truth value interaction and the Negation-by-Delay interaction were significant [both $F_1(1, 15) > 10.0, p < .01$, both $F_2(1, 78) > 6.7, p < .01$], but not the Delay-by-Truth value interaction (both $F < 1$). The three-way interaction was only marginally significant in the by-participant analysis [$F_1(1, 15) = 4.1, p < .07, F_2(1, 78) = 1.6, p > .20$]. The separate analyses for the two delay conditions produced a significant main effect of negation [$F_1(1, 15) = 16.6, p < .01, F_2(1, 39) = 26.9, p < .001$] and a significant Negation-by-Truth value interaction [$F_1(1, 15) = 21.5, p < .001, F_2(1, 39) = 9.0, p < .01$] only for the short-delay condition. No significant effects appeared in the long-delay condition [all $F_1(1.15) < 2.0, p > .19, F_2(1, 39) < 1.9, p > .18$].

In summary, the behavioral data show the expected Negation-by-Truth value interaction in both delay conditions, for latencies as well as error rates. The expected main effect of negation was also observed, but in the error rates it was only significant for the short delay. A stronger impact of negation for the short than for the long delay is also indicated by the significant Negation-by-Delay interaction in the latency and error analyses. Affirmative versions always lead to shorter response times and lower error percentages than negative versions. However, these differences were greater in the short-delay compared to long-delay conditions.

ERPs Evoked during Sentence Reading

The first and only point at which affirmative and negative sentences differed was the presentation of the affirmative "ein" ("a") and the negative "kein" ("no"). The subject noun followed 600 msec after the onset of "ein"/"kein." Figure 1 shows the grand-average ERPs starting from "ein"/"kein" up to a second after the presentation of the subject noun for selected electrodes.

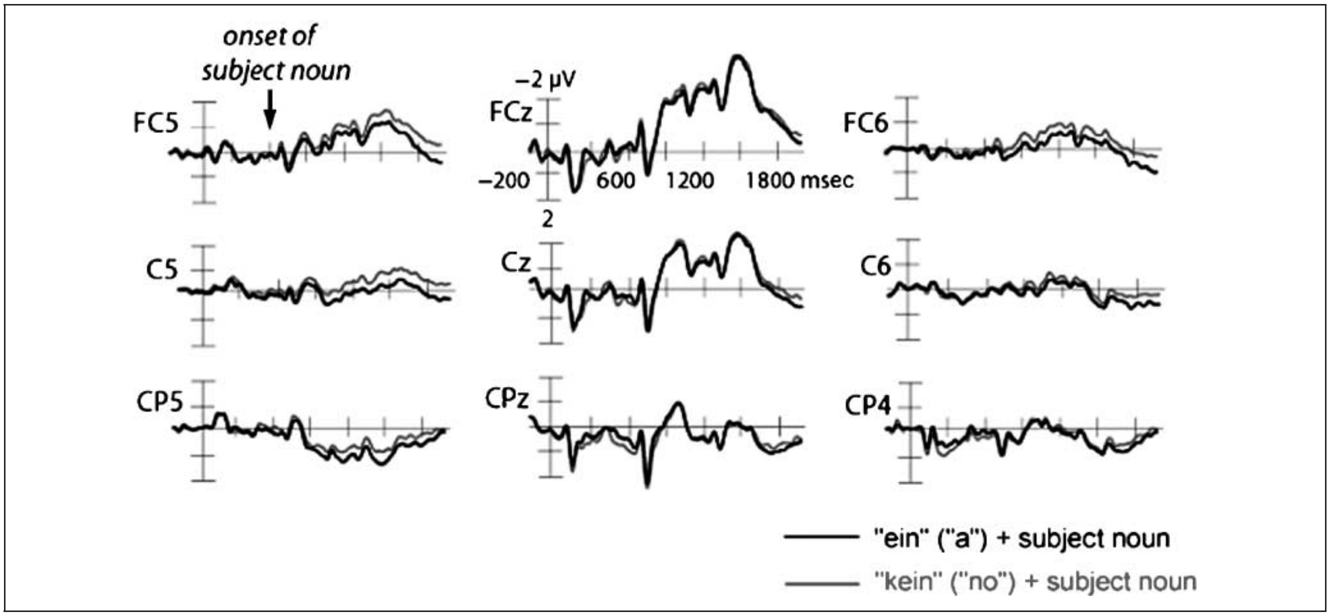


Figure 1. Grand mean averages related to ''ein''/''kein'' (''a''/''no'') and the following subject noun onset for selected electrode leads.

The presentation of ''ein''/''kein'' is associated with an N1–P2 complex followed by a negativity and by a posterior positive shift that is more pronounced for negative than for affirmative sentences starting at the P2 component. The 50-msec time-step ANOVAs with the factors negation and position revealed an onset of this effect at 50 msec after onset of ''ein''/''kein.'' The enhanced positive shift for ''kein'' extended over the following six 50 msec time windows. Accordingly, all six time windows ranging from 50 to 350 msec after onset of ''ein''/''kein'' revealed a main effect of negation [for all $F(1, 15) > 4.8$, $p < .05$]. There were no interactions of negation and position or negation and hemisphere except for the time window ranging from 200 to 250 msec after onset of ''ein''/''kein'' [$F(1, 15) = 5.73$, $p < .01$]. This time window only revealed an effect of the presentation of ''ein''/''kein'' for anterior [$F(1, 15) = 8.77$, $p > .01$] but not for posterior sites ($F = 2.0$).

ERPs for subject nouns during sentence reading are also associated with an N1–P2 complex followed by a widely distributed negative shift (see Figure 1). Here subject nouns following ''kein'' elicited more negative amplitudes than those following ''ein.'' In order to test a possible lateralization of this effect, we calculated 50-msec time-step ANOVAs with the factors negation and hemisphere as described in the Methods section. This analysis revealed an onset of this negative effect at 850 msec after onset of ''ein''/''kein,'' which is 250 msec after the onset of the subject noun presentation. Further examination of the negative shift using 50-msec time-step ANOVAs confirmed enhanced negativity for negated nouns in all time windows up to 2000 msec after the onset of ''ein''/''kein,'' which is 1400 msec after the onset of the subject noun presentation. Consequently, a main effect of negation was observed in a time window ranging from 850 to 2000 msec after onset of ''ein''/''kein'' [for all $F(1, 15) > 5.4$, $p < .05$]. There were no interactions of the factor negation with the factors region and/or hemisphere.

ERPs Evoked by the Picture

Figure 2 illustrates the ERPs evoked by picture presentation. For better clarity, the ERPs for the four versions are shown separately for the two delay conditions (short: Figure 2A; long: Figure 2B). Generally, all waveforms are characterized by an N1–P2 complex followed by a broad negativity starting about 200 msec after picture onset. It appears as a frontal negative effect. A peak at 300 msec can be separated from a parietal negativity with a peak at 400 msec. We will refer to the former effect as N300 and to the latter as N400. Amplitudes of both ERP deflections are, by virtue, equally sensitive to the experimental manipulation. The N300 over frontal electrodes is followed by a negative shift between 400 and 550 msec for true affirmative and false negative conditions. An early time window of the broad negativity including the N300 and the beginning N400 effect (250–400 msec) and a late time window including the negative shift and the preceding N400 (400–550 msec) were analyzed to account for the negative-going ERP effects up to 550 msec. The separation of three different components in two consecutive time windows is solved with respect to the specific topography of the frontal N300 and the negative shift on the one hand and the posterior N400 on the other hand. The N400 was followed by a positive-going ERP component for parietal electrode positions. A time window ranging from 550 to 1000 msec was applied to the analysis of this late positivity.

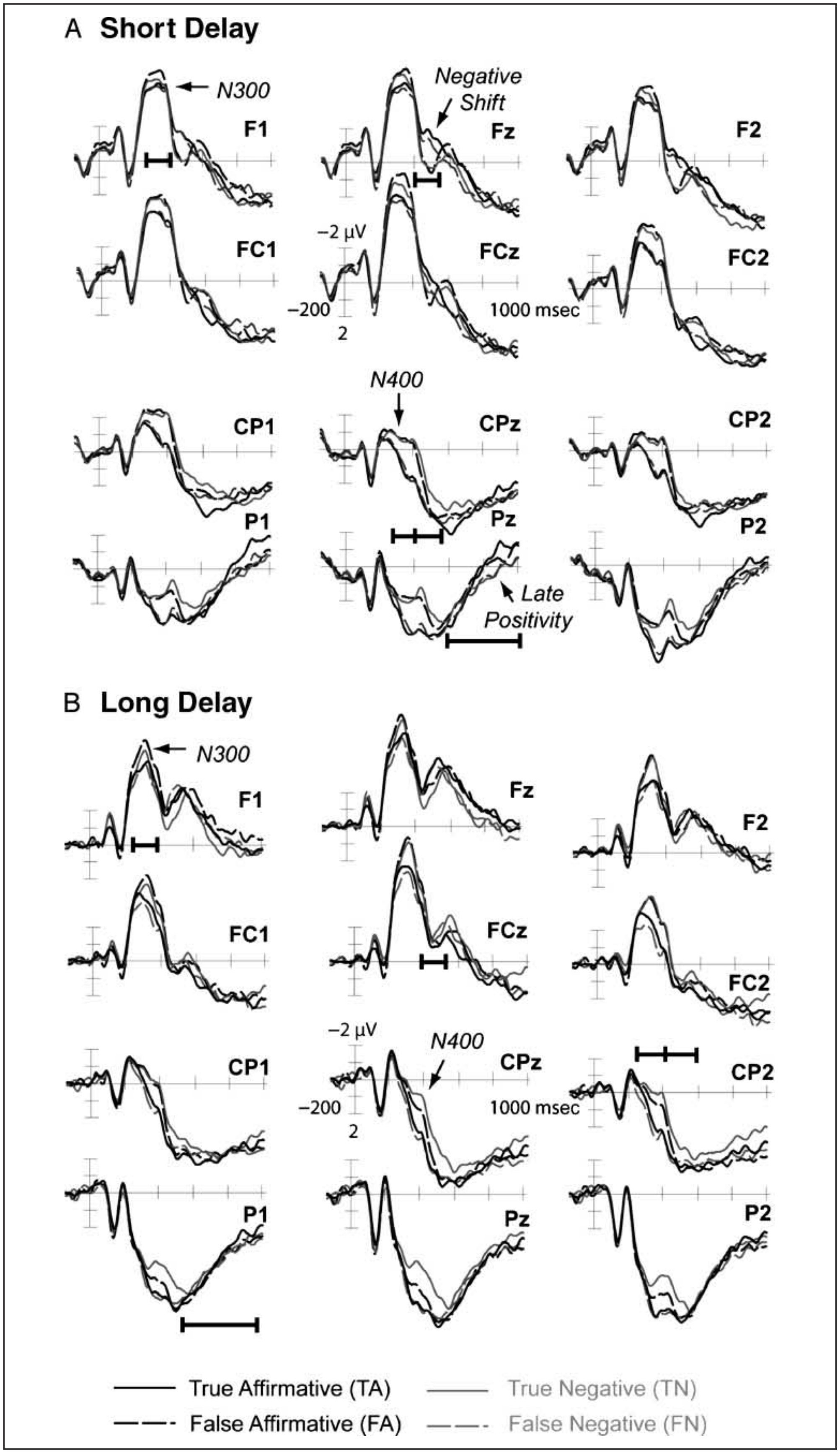


Figure 2. Grand mean averages related to picture onset. (A) ERPs elicited in the short-delay conditions for selected anterior and posterior electrode leads. (B) ERPs elicited in the long-delay conditions for the same electrode leads. Time windows applied to analyze ERP effects are marked.

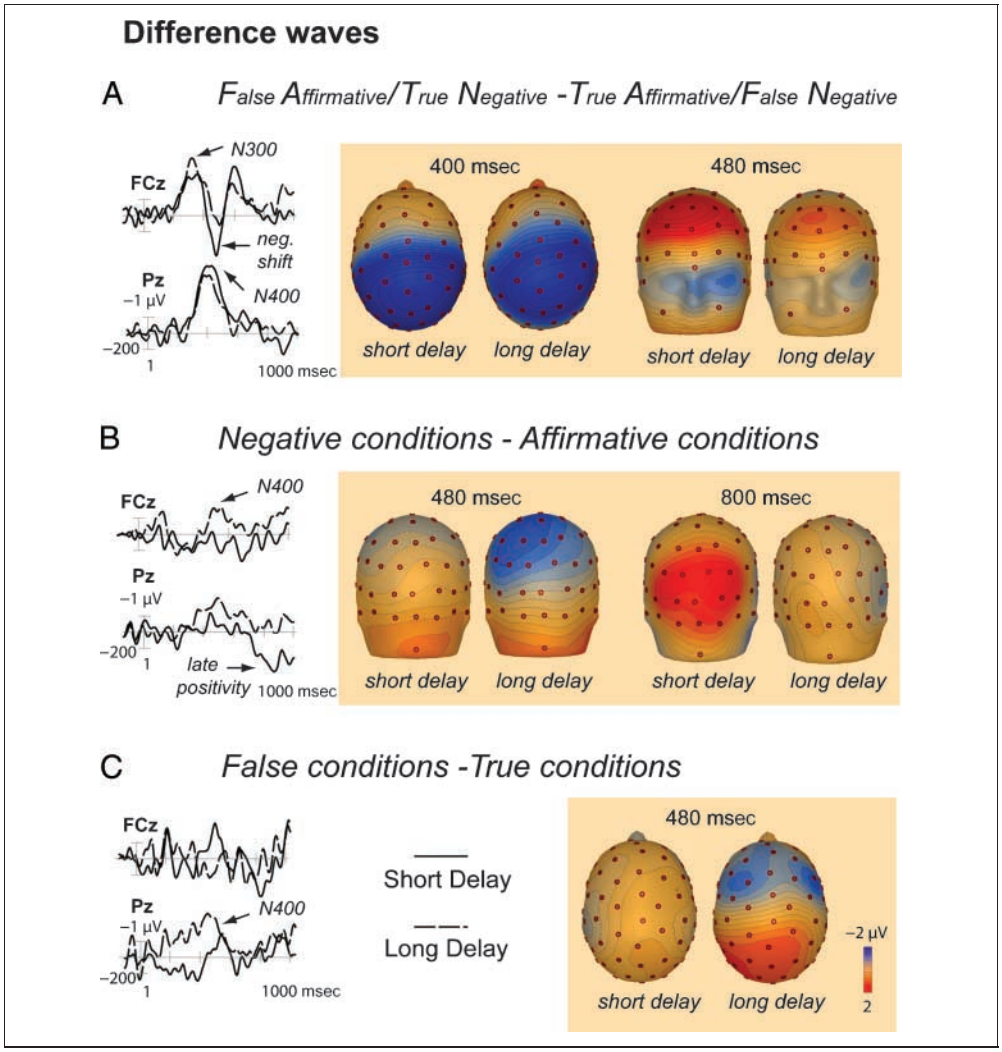


Figure 3. Difference waves and scalp topographies. (A) The negation by truth value interaction. Effects were found for the N400 component in both delay conditions, and for the negative shift in the short-delay conditions. (B) Main effects of negation, which were found for the late positivity in the short-delay conditions and for the N400 in the long-delay conditions. (C) Main effects of truth value, which were only found in the N400 for long-delay conditions.

N300/beginning N400 (250–400 msec). In both delay conditions the N300 and beginning N400 ERPs for the four experimental conditions can be separated into two groups (cf. Figure 3A and 3B), the priming group [true affirmative (TA) and false negative (FN) conditions] and the nonpriming group [false affirmative (FA) and true negative (TN) conditions]. However, as the interaction of Negation-by-Truth-value-by-Region-by-Delay proved to be significant [$F(1, 15) = 4.5, p < .05$], the two delay conditions were analyzed separately.

SHORT DELAY. For the short-delay condition, the grouping of primed and nonprimed conditions was confirmed by a significant Negation-by-Truth value interaction [$F(1, 15) = 28.6, p < .001$] in the early time window of the broad negativity (250–400 msec). There were no main effects of negation ($F < 1$) or truth value [$F(1, 15) = 1.5, p > .22$] in this time window. Further analyses of the negation and truth value effects for the different conditions revealed prominent effects of negation for true [$F(1, 15) = 11.6, p < .01$] and false conditions [$F(1, 15) = 20.3, p < .001$] as well as effects of truth value for affirmative [$F(1, 15) = 50.3, p < .001$] and negative [$F(1, 15) = 11.2, p < .01$] conditions. For affirmative sentences, mean ERP amplitudes elicited by false versions were more negative compared to ERP amplitudes elicited by true versions. By contrast, for negative sentences, ERP amplitudes for the true versions were higher than ERP amplitudes for the false versions. Thus, in accordance with former studies (Hald et al., 2004; Kounios & Holcomb, 1992; Katayama et al., 1987; Fischler et al., 1983), and in accordance with our predictions, primed conditions (TA, FN) were associated with smaller N400 amplitudes than nonprimed conditions (FA, TN). When contrasting primed conditions (TA, FN) or nonprimed conditions (FA, TN), no significant ERP effect was found for this time window (all: $F < 1$).

LONG DELAY. For the long-delay condition, the powerful priming effect on ERPs is also prominent as revealed by a significant Negation-by-Truth value interaction [$F(1, 15) = 17.2, p < .001$], but here it is supplemented by an effect of negation as confirmed by a Negation-by-Region interaction [$F(1, 15) = 9.4, p < .01$]. Follow-up comparisons revealed effects of truth value for negative [$F(1, 15) = 15.1, p < .001$] and affirmative conditions [$F(1, 15) = 5.2, p < .05$] as well as an effect of negation for true conditions [$F(1, 15) = 11.0, p < .01$]. For false conditions, only a marginal effect of negation was observed [$F(1, 15) = 3.2, p = .09$]. In addition, a main effect of negation was observed for anterior [$F(1, 15) = 6.0, p < .05$] as well as posterior regions [$F(1, 15) = 13.5, p < .01$].

Late N400 time window/negative shift (400–550 msec). A Negation-by-Truth-value-by-Region-by-Delay interaction [$F(1, 15) = 5.6, p < .01$] points to differences in the delay conditions regarding effects on amplitudes elicited between 400 and 550 msec.

SHORT DELAY. In the short-delay condition, an interaction of negation, truth value, and region was significant [$F(1, 15) = 10.9, p < .01$]. For both regions, the Truth-value-by-Negation interaction was significant [posterior sites: $F(1, 15) = 5.91, p < .01$; anterior sites: $F(1, 15) = 9.50, p < .01$]. At posterior sites, the conditions with priming (TA and FN) differed from those without priming (FA and TN) by a reduced negativity as in the early N400 time window [for all $F(1, 15) > 11.6, p < .05$]. In contrast, at anterior sites, the conditions with priming (TA and FN) led to enhanced negativity compared to those without priming (FA and TN). For affirmative sentences, true versions resulted in a larger amplitude than false versions [$F(1, 15) = 5.2, p < .05$], but for negative sentences, false versions resulted in a larger amplitude than true versions [$F(1, 15) = 9.8, p < .01$]. The Negation-by-Truth value interaction separates ERPs for anterior and posterior electrodes in the late N400 time window. Only the posterior deflection is equivalent to the classical N400 effect observed in previous ERP studies, whereas the anterior sites show a reversed pattern.

LONG DELAY. For long-delay conditions, no Negation-by-Truth value interaction was found [Negation × Truth value: $F(1, 15) < 1$; Negation × Truth value × Region: $F(1, 15) = 1$]. The separation of primed and nonprimed conditions that shaped the early N400 window for both delay conditions as well as the later time window for the short delay can no longer be detected for the long-delay conditions. Instead, Negation-by-Region [$F(1, 15) = 7.2, p < .05$] and Truth-value-by-region [$F(1, 15) = 16.5, p < .01$] interactions were found. The main effect of negation at posterior sites in the early N400 time window continues at posterior sites ($F = 9.7, p < .01$). Pictures after negative sentences elicited enhanced N400 amplitudes relative to pictures after affirmative sentences. Besides, differences for true compared to false conditions were found for the anterior region [$F(1, 15) = 10.2, p < .01$], as well as for the posterior region [$F(1, 15) = 24.8, p < .01$]. Both revealed more negative ERPs for true compared to false conditions.

In sum, in addition to the N400 effect, the results show a N300 deflection, which might be specific to picture processing. Although some authors found that the N300 and the N400 are differentially sensitive to experimental variables (e.g., Federmeier & Kutas, 2002; McPherson & Holcomb, 1999), in the present study, both components are equally modulated by the experimental manipulation. Therefore, we will summarize both the N300 and the N400 as the N400 effect in the following discussion. For the short-delay condition, the N400 does not reflect the negation or the truth value of the sentence, but rather, whether or not picture processing was primed by sentence processing. In contrast, for the long-delay condition, differences in picture processing following negative and affirmative sentences, as well as differences for true and false conditions, were shown in both time windows analyzed for the N400 effect (compare Figure 3B and C).

Late positivity (550–1000 msec). A main effect of negation was found in the time window of the late positivity [$F(1, 15) = 6.0, p < .05$]. Pictures following negative sentences elicited an enhanced late positivity. A marginal interaction of negation and delay [$F(1, 15) = 3.7, p < .07$] suggested different late positive effects as a function of delay. A three-way ANOVA for the short delay produced a main effect of negation [$F(1, 15) = 8.4, p < .05$], whereas the one for the long delay did not reveal such an effect ($F < 1$). Thus, only for the short-delay conditions did late ERP effects reflect processing of negation (cf. Figure 3B).

DISCUSSION

The present study was concerned with ERP correlates of negation in a sentence–picture verification paradigm. This paradigm offers the possibility to present neutral sentences such that neural correlates of on-line processing of negation can be investigated independent of sentence priming and sentence verification processes. In addition, the paradigm allows to manipulate the time that is available for sentence comprehension prior to verification, thereby offering insights into the temporal characteristics of the comprehension process associated with negative sentences.

Effects Observed during Sentence Reading

ERPs for affirmative and negative sentences differed for the penultimate "ein"/"kein" ("a"/"no") and for the sentence-final subject words. The former effect is difficult to interpret, as "kein" is longer and less frequent than "ein," and both variables are known to modulate early ERP amplitudes (e.g., Hauk & Pulvermüller, 2004; Sereno, Brewer, & O'Donnell, 2003). The later effect might either reflect late processing related to the negation marker or processing related to the negated/affirmed noun. Adjusted to the presentation of the negation marker, the effect starts relatively late (750 msec after the onset of ''ein''/''kein''). Late ERP deflections in sentence comprehension have been previously related to syntactic (e.g., Osterhout & Holcomb, 1992) or semantic (e.g., van Herten, Chwilla, & Kolk, 2006) reanalysis processes. Conditions that undergo such reanalyses elicit enhanced positive shifts. However, in the present experiment, the affirmative condition—which should demand less processing effort as shown in a recent brain imaging study (Carpenter et al., 1999)—elicits more positive-going waveforms than the negative condition. Therefore, it appears unlikely, that the negative shift reflects syntactic reanalysis related to the negation marker. Hence, if the negative shift is related to the onset of the negation marker at all, then it probably has a different source. One possibility is that it relates to the family of negative slow waves that are associated with memory processes (e.g., Rösler, Heil, & Röder, 1997). In that respect, the negative shift might indicate specific retrieval processes after encountering a negation marker. As was discussed earlier, the two-step simulation hypothesis assumes that comprehenders first simulate the state of affairs that is being negated when processing a negative sentence. Accordingly, negation is not integrated into the meaning representation until rather late in the comprehension process. Nevertheless, adequate processing of a negative sentence requires that comprehenders keep in mind that the sentence contained a negation marker. The observed negative shift might indicate retrieval processes of this sort.

Alternatively, the negative shift may also be related to the processing of the negated/affirmed noun. Adjusted to the onset of the final word, the effect is in the time range of the N400, but it does not correspond to the usual topography and time course of this component. The negative shift is neither lateralized nor pronounced for posterior sites, its time course is longer than one would expect for an N400, meaning that it rather reflects a continuous slow ERP deflection than a distinct peaking component. Nevertheless, one might associate the enhanced negativity with enhanced processing effort for words directly following a negation marker. As of yet, it is not clear, exactly why negated nouns should require more effort. It is possible that the difficulties have something to do with lexical access. Alternatively, they may again reflect rehearsal processes that compared to the ones discussed in the previous paragraph are less general but aim at keeping available specifically the negated noun for further processing. In line with this interpretation, current work on negation comprehension has shown that negated nouns are not always suppressed but rather kept available for subsequent context integration (Shuval, 2006; see also Giora, Fein, Aschkenazi, & Alkabets-Zlozover, 2007; Giora, 2006).

Finally, one may assume that the effect is specific to our sentence–picture verification paradigm in the sense that comprehenders built expectations on what to find in the picture. For an affirmative sentence to be true, the object mentioned in the grammatical subject position should be present in the picture, but for a negative sentence, it should be absent. Expectations about the presence of an object may be less difficult than expectations about the absence of an object. However, it should be noted that, with our materials, affirmative and negative conditions did not differ with respect to what to expect in the picture. The mentioned object was present in half of the cases for both types of sentences. Thus, making predictions on the basis of the content of the sentence would not be a very useful strategy. Furthermore, the effects that we observed for picture processing, in particular, the differences between the two delay conditions (see below), speak against the use of such a *simple* strategy.

Taken together, we observed immediate effects of negation in the ERPs during sentence processing, suggesting that a negation marker such as ''kein'' affects subsequent processing as soon as it is encountered. As of yet, it is unclear whether this effect reflects general retrieval processes by which the comprehender keeps in mind that a negation had been encountered during reading, or more specific processes that are related to the processing of the negated noun. In the following, we will show that even though we observed evidence that negation immediately affects word processing, its effect on the meaning representation that comprehenders build appears to be delayed.

Effects Observed during Picture Verification

After sentence reading, we investigated the responses to a picture that either matched or mismatched the situation described in the affirmative or negative sentence just read. The temporal dissociation of comprehension and verification allowed tracking the temporal characteristics of the comprehension process. Crucially, we manipulated the delay with which the picture was presented after the sentence. In the short-delay condition, the picture appeared 250 msec after the final word of the sentence. In the long-delay condition, the delay was 1500 msec. Different ERP components were sensitive to our manipulations. A frontal N300 and a posterior N400, which were observed in both the short- and the long-delay conditions and which showed comparable effects, are summarized as the N400. A frontal negative shift and a posterior late positive shift were restricted to the short-delay condition. In the following, we will first discuss the prominent Negation-by-Truth value interaction observed in the N400 time window as well as in the behavioral data in both delay conditions. Subsequently, we will address differences between the two delay conditions that, in our view, support the assumption that negation is being integrated at a rather late state in the comprehension process.

The N400 results were largely as expected. We observed in both delay conditions Negation-by-Truth value interactions, with reduced N400 amplitudes in the true compared to the false versions for affirmative sentences, but enhanced N400 amplitudes in the true compared to the false versions for negative sentences. N400 reduction was accompanied by shorter response times and less errors (the later only in the short delay). In behavioral studies employing different kinds of verification tasks, this effect is traditionally interpreted as reflecting the complexity of a step-by-step comparison process that presumably produces the truth value of the sentence (for a detailed description of the models, see Carpenter & Just, 1975; Clark & Chase, 1972). However, the structure of the present materials, as the one employed in other ERP studies, advises an interpretation in terms of priming: For affirmative sentences, the depicted object in the picture is mentioned in the sentence only in the true version, whereas for negative sentences, the depicted object is mentioned in the sentence only in the false version (cf. Table 1). Furthermore, from the perspective of the two-step simulation hypothesis, the simulation that comprehenders presumably create at the beginning of the comprehension process corresponds to the picture in the true version for affirmative sentences but to the picture in the false version for negative sentences. Thus, the Negation-by-Truth value interaction is not surprising and probably reflects the fact that picture processing is primed by sentence processing in the true affirmative and false negative conditions but not in the false affirmative and true negative conditions.

Interestingly, we did not find strong evidence that picture priming is reduced in the long-delay relative to the short-delay condition. As far as the response times and the N400 amplitudes in the early time window were concerned, Negation-by-Truth value interactions of similar magnitude were observed in the two delay conditions. This indicates that sentence–picture priming affected processing to a similar degree in the two delay conditions. The negative finding with respect to an attenuation of the priming effect is particularly interesting for an interpretation of the results in terms of the two-step simulation hypothesis. It suggests that the simulation of the negated state of affairs (that is presumably created in a first step when processing a negative sentence) is not being inhibited when the comprehender (in a second simulation step) turns toward the actual state of affairs. To illustrate, when a comprehender reads a sentence such as ''In front of the tower there is no ghost,'' he or she presumably simulates a ghost in front of a tower in a first step (simulation of negated state of affairs) followed by an empty tower in a second step (simulation of actual state of affairs). When then a picture is presented that shows a ghost in front of a tower, picture processing is facilitated relative to a condition in which the picture shows a different object in front of a tower. This holds, even if the picture is presented with a long delay of 1500 msec, in which case the comprehender can be expected to have started the second simulation step. The ongoing facilitation under this interpretation then indicates that the comprehender does not inhibit the first simulation when turning to the second. Interestingly, this view is in line with a recent proposal by Giora and colleagues, as described earlier in the Discussion.

Our specific predictions with regard to main effects of negation were largely supported by the data. According to our hypothesis, comprehenders have not integrated the negation into the sentence meaning when the picture comes up shortly after sentence processing. Indeed, the short-delay condition replicated earlier ERP studies employing a sentence verification task in that no pure negation effects were observed in early time windows (Hald et al., 2004; Kounios & Holcomb, 1992; Fischler et al., 1983). However, adequately responding to the verification task requires taking into account the negation. As the negation has not yet been integrated by the time the picture comes up in the short-delay condition, this has to be made up for during or after picture processing. In line with this, a negation effect was observed in later time windows in the ERPs. More specifically, we found a negation effect in a late positivity, starting 550 msec after stimulus onset. For the long-delay condition, we predicted early effects of negation in the ERPs because comprehenders presumably have finalized integrating the negation into the meaning representation when the picture is presented with considerably delay. Indeed, we *did* find main effects of negation in early time windows in the ERP, starting 250 msec after picture onset. No main effect of negation was observed in later time windows in this condition. Thus, the results support our main hypothesis that integrating the negation into the sentence meaning takes a substantial amount of time, and that this is the reason why previous ERP studies employing a sentence verification paradigm did not observe main effects of negation, despite the fact that participants correctly responded in the verification task.

The observed behavioral effects also line up nicely with this interpretation. In the response times, we observed a significant delay-by-negation interaction, indicating that negation prolonged response times to a stronger degree in the short- than in the long-delay condition. Similarly, error rates were affected by negation only in the short-delay condition. The finding that responses are particularly long and error-prone in the negated short-delay condition supports the idea that additional processing is required specifically in this condition. The remaining main effect of negation in the long-delay condition underpins the theoretical assumptions that the representation of a negated sentence may be more complicated than the one of the appropriate affirmative sentence. Interestingly, the main effect of negation is a good example of how behavioral data and electrophysiological recordings may support each other. On the basis of the behavioral data alone, it seems that there is no difference between the two delay conditions regarding the processing of negation. However, the ERPs tell us that similar effects in the verification times are caused by qualitative differences in negation processing.

In the previous discussion, we interpreted the posterior late positive shift (that in the short-delay conditions was modulated by whether or not the sentence was negative) as reflecting processes associated with the planning of the verification response. Given that the effect started 550 msec after picture onset, the question arises whether this interpretation makes sense, or whether the effect rather reflects processes *after* response preparation. The shortest response times were observed in the true affirmative condition. Here participants required, on average, 676 msec to respond. Thus, even in this condition, the observed late positivity preceded the response by approximately 125 msec in average. Moreover, in the negative conditions, where the enhanced late positivity was observed, the effect preceded the average response by more than 320 msec. We therefore consider it safe to interpret the late positivity as reflecting processes that are associated with the planning of the verification response.

In our view, the late positivity for negated sentences in the short-delay condition might be an instance of the P600 effect, a centro-parietal positive wave with an onset between 500 and 800 msec. Initially, the P600 has been reported to reflect syntactic reanalysis processes (Osterhout & Holcomb, 1992). More recently, the P600 has also been observed for semantic anomalies (van Herten, Kolk, & Chwilla, 2005; Kupperberg, Sitnikova, Caplan, & Holcomb, 2003). For example, final words in sentences like (6) do not lead to enhanced N400 amplitudes, but to enhanced P600 amplitudes.

(6) The deer was chasing the hunter.

To account for this result, van Herten et al. (2006) proposed that the P600 generally reflects reanalysis processes that optimize behavioral outcome, particularly in language perception. The authors argue that a fast semantic heuristic produces the most plausible interpretation solely based on content words [e.g., according to the plausibility heuristic, the hunter is chasing the deer in (6)]. If a sentence contains content words that semantically fit together, this is reflected in a reduced N400 regardless of syntactic specifications. A slower parsing algorithm then produces the exact sentence interpretation. If both outcomes clash, the language system will reprocess the sentence, as reflected in enhanced P600 amplitudes.

A conflict monitoring approach to the P600 as proposed by van Herten et al. (2006) might also apply to the late positivity observed in the short-delay conditions. Applied to our experimental task and theoretical background, the fast heuristic presumably only takes into account whether or not the depicted scene matches a simulation that the comprehender has available. This is reflected in reduced N400 amplitudes for both the true affirmative version (where the picture matches the simulation of the described scenes) and the false negative version (where the picture matches the simulation of the negated state of affairs). However, as we have also shown, negation is immediately encoded during sentence reading, as reflected in a negative shift for negated objects in the ERPs, and this information is used to catch the truth value information necessary to solve the verification task. Thus, the slower-parsing algorithm also takes into account whether or not the sentence contained a negation. For the affirmative sentences, the results of the two processes are the same. In contrast, for negative sentences, the results of the two processes are in conflict. According to the fast heuristic, the correct answer is true in the false conditions and false in the true conditions. Hence, a P600 reflecting reanalysis elicited by two clashing interpretations is observed with negative sentences. Crucially, the late positivity demonstrates that negation, indeed, modulates the verification decision well before a response is executed.

The question arises why such a late positivity effect of negation was not observed in one of the previous ERP studies employing a sentence verification paradigm. Possibly, a lack of power is to blame. In the previous studies, a much smaller number of electrode leads was used, ranging between 4 (Katayama et al., 1987) and 28 electrodes (Hald et al., 2004). Crucially, in our study, the negation effect is only significant when averaged over all 44 electrodes. The observation of a late positive effect in sentence verification that did not reach significance (Fischler et al., 1983) might also point in that direction. Taken together, the present results bridge the gap between the ERP results that did not reflect negation and the correct verification decisions that have been previously reported. If negation does not affect processes reflected in the N400 component, it modulates processes reflected in a small late positive ERP effect. This additional neurocognitive processing for negative conditions in the short delay presumably causes the longer reaction times observed for the very same conditions.

Finally, a finding that has been previously not observed in the neurolinguistic research on the processing of negated sentences has to be discussed. Restricted to the short-delay conditions, we found a frontal negative shift between 400 and 550 msec for true affirmative and false negative sentences. This negative shift occurred only in the primed conditions (true affirmative and false negative), but was not found in nonprimed conditions (false affirmative and true negative). Presumably, the former conditions elicit a strong bias in favor of ''true'' responses. Hence, one might speculate that after monitoring this possible response bias, the language processing system might inhibit overhasty responses in these primed conditions. Frontal ERP effects have been repeatedly related to response inhibition (see Falkenstein, 2006; Yeung, Botvinick, & Cohen, 2004 for recent overviews). However, those inhibition effects are usually associated with go–nogo paradigms, which are difficult to compare with the present design. Thus, future research is needed to clarify the specific role of the frontal negative shift we observed for primed pictures in the present experiment.

Conclusion

In a study employing the sentence–picture verification paradigm, we investigated ERP correlates of negation during and after sentence reading. The results allow for several conclusions: First, negation is recorded early on in the comprehension process as indicated by an enhanced negativity starting 250 msec after the onset of a negated noun in the ERP. Further investigations are required to clarify whether this effect reflects memory or word comprehension processes. Second, negation does not seem to be integrated into the representation of the sentence meaning right away: Shortly after reading a negative sentence, we observe priming effects that are independent of whether the sentence contains a negation or not, and therefore, cannot reflect processes that operate on the meaning representation of the sentence as a whole. Third, at a later point in the comprehension process, negation does get integrated into the representation of the sentence meaning: Negation effects emerge in the EEG at an earlier point in time, and although the priming effects persist, the overall task difficulty decreases especially for the negative versions. Fourth, in conditions in which negation has not yet been integrated into the ongoing sentence interpretation, verification decisions appear to be modulated by a time-consuming reanalysis process.

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Notes

1. Notice that for Japanese phonograms the verb phrases "is" and "is not" both consist of two letters.
2. Readers who are familiar with our previous behavioral negation studies should note that with the present materials, the depicted state of affairs in the negated conditions never exactly corresponds to the actual state of affairs. Thus, for "In front of the tower there is no ghost," the participant either sees a picture with a ghost in front of the tower (primed condition) or of a tower with something else in front (unprimed condition), but never an empty tower. Accordingly, we do not expect facilitation in the unprimed-negative long-delay condition, where the comprehender presumably shifts attention away from the negated state of affairs and onto the actual state of affairs.

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