Bridging the gap between the semantic N400 and the early old/new memory effect

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We set out to investigate the extent to which semantic integration processes during language comprehension indexed by the N400 component affect subsequent declarative memory processes as revealed by the putative event-related potential correlates of familiarity and recollection. To this end we designed an incidental recognition memory test whose study material was composed of sentences that were either correct or contained a semantic or syntactic violation. By this means it was possible to examine the mnemonic consequences of the N400 amplitude at study. We found a significant correlation between the amplitude of the N400 at encoding and the magnitude of the familiarity-related early old/new effect at test. It is argued that the processes that contributed to N400 generation increase the likelihood of familiarity-based recognition memory. *NeuroReport* 18:1009–1013 © 2007 Lippincott Williams & Wilkins.

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Introduction

In language event-related potential (ERP) research, a negative component peaking around 400 ms after stimulus onset (the N400) has been shown to vary systematically with the processing of potentially meaningful stimuli and is reduced by a variety of factors that increase these items' predictability in the local context at word or sentence level [1,2]. This effect has been explained by a preactivation of the semantic concepts of forthcoming words by a mechanism of spreading activation [3]. Furthermore, it has been proposed that the N400 represents the access to semantic long-term memory and the strong activation of a concept [4]. According to this proposal, an N400 to semantically incongruent words reflects the enhanced effort to activate a word's concept, as no contextual preactivation in semantic memory by facilitation processes has taken place.

No semantic N400 can be observed in sentence contexts containing grammatical violations. Friederici and colleagues [5] found that processing sentences whose terminal verb was incongruent with the preceding context owing to a double violation, that is, a syntactic phrase structure violation and a semantic violation, elicited no N400. The absence of an N400 for words that are syntactically and semantically incongruent suggests that words that are not syntactically licensed are not semantically integrated during on-line language comprehension. Syntactic processing problems are associated with two other scalp recorded components instead: an early left anterior negativity followed by a late component, the so-called P600 [6] that is assumed to reflect late syntactic integration difficulties that require controlled processes of syntactic reanalysis and repair.

The main goal of this study was to examine whether the semantic integration processes during language comprehension in the N400 interval have an effect on subsequent declarative memory processes.

An example of declarative memory is recognition memory, which is commonly thought to consist of two processes, familiarity and recollection. A variety of studies suggest that the two processes of recognition can be mapped onto two qualitatively distinguishable ERP components. In recognition memory tasks a robust ERP difference between correctly judged old and new items, the so-called old/new effect, has been found that starts around 300 ms after item onset and takes the form of more positive going waveforms for correctly recognized old compared with correctly rejected new items. An early old/new effect between 300 and 500 ms can be dissociated from a later effect with a more parietal topography between 400 and 800 ms (e.g. [7]). The early component has been associated with the assessment of the overall similarity between study and test items, a form of memory that is accompanied by a subjective feeling of familiarity or knowing. This effect is assumed to arise from the attenuation of a frontally focused N400-like component [8] presumably reflecting the facilitated access to conceptual and perceptual information related to the test item [9]. Moreover, it has been dissociated from ERP correlates of pure implicit memory processes [10]. In contrast, the parietal old/new effect that can be observed in situations where participants are capable of remembering detailed information about studied items is related to recollection [11].

Taken together, under the notion that similar processes are engaged during semantic integration and familiarity-based

recognition, we aimed to find an association between the amplitude of the N400 component at study and the ERP correlate of familiarity at test.

Methods

Participants

Participants were 16 right-handed undergraduate students [eight women; mean age 22.8 years (range: 19–28)] who were paid for participation. All participants had normal or corrected-to-normal vision.

Electroencephalography recording

The electroencephalography (EEG) was continuously recorded from 61 Ag/AgCl scalp electrodes referenced to the left mastoid electrode, and re-referenced off-line to the average of the mastoids (electrode impedances $<5\,k\Omega$, sampling rate of 500 Hz, bandpass filter to 100 Hz). Vertical and horizontal electrooculograms were recorded by a bipolar montage. Further off-line data processing included a digital high-pass filter set to 0.5 Hz and an additional low-pass filter set to 12 Hz (3 dB cut-off).

Stimulus material

The 'study phase' included a total of 96 sentences: correct sentences [e.g. Die Tür wurde geschlossen (approximate literal translation: *The door was being closed*)], semantically incorrect sentences [e.g. Der Ozean wurde geschlossen (*The ocean was being closed*)], syntactically incorrect sentences that contained a phrase structure error [e.g. Das Geschäft wurde am geschlossen (*The shop was being on closed*)] and correct filler sentences containing a full prepositional phrase [e.g. Der Laden wurde am Samstag geschlossen (*The store was being on Saturday closed*)]. The filler sentences were not included in the analyses.

Procedure

All sentences were presented via loudspeakers. Mean duration was 1700 ms. Three seconds after the final verb, the task was to indicate via button press whether a sentence contained a violation or not. After a delay of 5 min participants were instructed about the upcoming test. We decided on an incidental memory test to avoid strategic encoding operations at study that might influence both semantic and syntactic processing. To prevent perceptual fluency for old words a cross-modal recognition memory task was used. The test phase included 288 words (144 nouns and 144 verbs). The 72 old nouns as well as the 72 old verbs were chosen from the three critical types of study sentences. The words were presented visually for 1000 ms and old and new words were matched in word frequency and length. Participants were given 2000 ms to respond by button press whether a seen word was old or new.

Data analysis

Behavioral data

In the study phase we analyzed the proportion of correct responses in the classification task. We performed a one-way repeated-measures analysis of variance (ANOVA) for the proportion of correct old responses (three levels: verbs from correct, semantically incorrect and syntactically incorrect sentences). Reaction time was defined as the interval between the appearance of the test item and the participant's key press. A one-way ANOVA for the four response categories relevant for the ERP analyses (correct old responses to verbs from the three conditions and new responses to NEW verbs) was conducted.

Event-related potential data

Study phase

Event-related potentials were computed for three different conditions (with the mean number of valid trials per condition given in parentheses): Correct (19), semantically incorrect (20) and syntactically incorrect (20) sentence endings. Epoch length was 800 ms starting with the onset of the final word of the sentence. As any prestimulus baseline would cover different word types, the first 50 ms after the onset of the critical word was used as a baseline to minimize the influence of the preceding word. To test our prediction of a differential involvement of different brain systems in processing correct, semantically incorrect and syntactically incorrect sentences, we performed an ANOVA with the factors CONDITION (three levels: correct, semantically incorrect and syntactically incorrect), TIME WINDOW [two levels: early (400–600 ms) vs. late (600–800 ms)] and ROI (region of interest) [two levels: central (FC3, FCZ, FC4, C3, CZ, C4, CP3, CPZ, CP4) vs. posterior (P3, PZ, P4, PO3, POZ, PO4, O1, OZ, O2)].

Test phase

ERPs were computed for four different conditions: recognized verbs from correct (14), semantically violated (12), and syntactically violated sentences (12) as well as new verbs (42). Epoch length was 1200 ms starting with the onset of the presented word. Prestimulus baseline was 200 ms. To test whether there were different recognition-related ERP characteristics caused by the different kinds of violations in the study phase, we performed an ANOVA for the verbs with the factors CONDITION (four levels: verbs from correct sentences, semantically violating verbs, syntactically violating verbs and new verbs), TIME WINDOW [two levels: early (450–550 ms) vs. late (600–800 ms)] and ROI (region of interest) [two levels: central (FCZ, CZ, CPZ) vs. posterior (P3, PZ, P4, PO3, POZ, PO4)]. For all ANOVAs, the Greenhouse–Geisser adjustment for nonsphericity was used when appropriate.

Results

Study phase

Behavioral data

All participants were highly accurate in classifying the sentences. The proportion of correct responses was 0.99 (SEM=0.005) for correct sentences, 0.99 (SEM=0.004) for semantically incorrect and 0.93 (SEM=0.007) for syntactically incorrect sentences. A main effect of CONDITION [$F(2,30)=5.12$, $P<0.05$] existed, indicating that the classification of the syntactically violated sentences was the most difficult one.

Event-related potential data

As illustrated in Fig. 1, processing verbs that violate a sentence semantically led to a typical N400 at centro-parietal electrode sites that was reduced for correct sentence endings and absent for syntactically violated sentences. Syntactic

violations are related to a later posteriorly distributed positivity (P600). A three-way ANOVA revealed main effects of CONDITION, [$F(2,30)=18.51$, $P<0.0001$] and TIME WINDOW, [$F(1,15)=30.94$, $P<0.0001$]. Furthermore, interactions of CONDITION and ROI [$F(2,30)=3.74$, $P<0.05$] and TIME WINDOW and ROI [$F(1,15)=16.01$, $P<0.01$] were obtained. Follow-up analyses were performed separately for both ROIs and time windows. At the central recording sites there was a significant difference in the early time window between the semantic and the syntactic violations, $F(1,15)=7.32$, $P=0.02$, and between the semantic violations and the correct sentence endings, $F(1,15)=5.55$, $P=0.04$, with the ERPs to semantic violations showing the largest N400. At posterior electrodes we found a significant difference in the late time window between the syntactic violations and both the semantically violated and correct sentences, $F(1,15)=5.84$, $P=0.03$ and $F(1,15)=54.42$, $P<0.0001$, respectively, with the syntactically violated verbs generating the largest *p*600. These results replicate findings from earlier studies using similar materials and task characteristics in the visual and auditory modality (e.g. [12]).

Test phase

Behavioral data

The repeated-measures ANOVA for the hit rates (three levels) revealed no differences between the three item types, $F(2,30)=1.23$, $P=0.30$ (0.65 for correct, 0.59 for syntactically violating and 0.61 for semantically violating verbs). The statistical analyses for reaction times also showed no differences between the four response categories relevant for the ERP analyses (old responses to OLD verbs from the three conditions and new responses to NEW verbs), $F(3,45)=2.37$, $P=0.10$ (1130 ms for correct, 1121 ms for syntactically violating, 1080 ms for semantically violating and 1172 ms for new verbs).

Event-related potential data

As illustrated in the middle column of Fig. 2, verbs that violated a sentence semantically led to an early old/new effect after a later parietal effect. In contrast, verbs from correct sentences showed only a smaller early and parietal old/new effect. For verbs from syntactically violated sentences there was neither an early nor a later parietal old/new effect.

A three-way ANOVA revealed main effects of TIME WINDOW [$F(1,15)=5.65$, $P<0.05$] and ROI [$F(1,15)=13.57$, $P<0.01$]. Furthermore, an interaction of TIME WINDOW and ROI [$F(1,15)=5.98$, $P<0.05$] and a three-way interaction of CONDITION, TIME WINDOW and ROI [$F(3,45)=2.96$, $P<0.05$] were obtained.

To further explore these interactions we performed pairwise comparisons of the levels of the condition factor separately for each of the ROIs and time windows. An old/new effect was found for the early time window and the

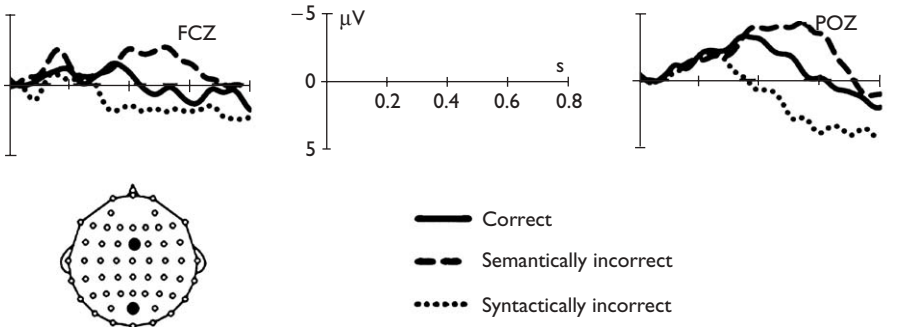

Fig. 1 Grand average event-related potentials for the critical verbs at a frontal and a parietal recording site.

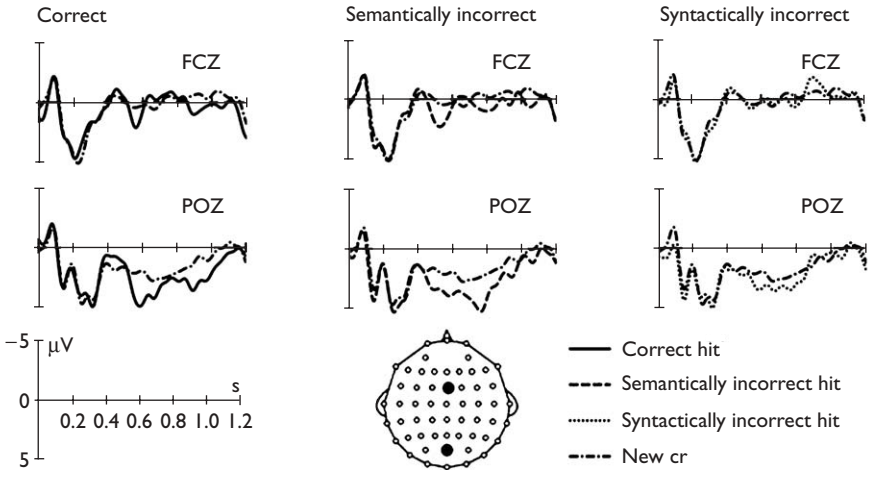

Fig. 2 Grand average event-related potentials for correctly recognized old verbs and correctly rejected new verbs at a frontal and a parietal recording site.

central ROI for the contrast between semantically violating old verbs and new verbs, $F(1,15)=7.10$, $P<0.05$. No other effects were obtained for the central ROI. In addition, at the posterior ROI in the late time window an old/new effect was obtained for verbs from the semantically violated sentences, $F(1,15)=5.82$, $P<0.05$, but not for the other two contrasts.

To further examine the relationship between the N400 and the test phase ERPs, we performed a correlation analysis between the mean amplitudes of the N400 in all three conditions in the study phase and the early and the parietal old/new effect at test phase. To increase the power of this analysis all trials across all three conditions were included in this analysis. The N400 in the study phase was operationally defined as the mean voltage in the time range in that the N400 was largest (i.e. 400 and 550 ms) at the FCZ recording site. The early old/new effect was quantified in the same time range at the same electrode as the difference between the mean amplitudes to old and new words, whereas the parietal old/new effect was quantified between 600 and 800 ms at electrode POZ. The data were normalized (by dividing the difference of each value from the within participant mean value by the standard deviation) to prevent biasing influences of pure amplitude differences over participants. By this means, we found a significant negative correlation between the N400 at study and the early old/new effect at test ($r=-35$, $P<0.01$). The larger the N400 at study, the larger was the difference between old and new items. This points to a striking relation between semantic integration processes during language comprehension and familiarity-based remembering during recognition, especially in consideration of the fact that no significant correlation between the N400 amplitude and the parietal old/new effect could be found ($r=-18$, $P>0.05$).

Discussion

This study examined the mnemonic consequences of semantic integration processes during language comprehension by investigating its influence on qualitatively different aspects of recognition memory, reflected in distinct spatiotemporal ERP components. Although no behavioral differences in reaction time and response accuracy of the recognition memory judgements were obtained, the amount of semantic integration as indexed by the N400 clearly predicts the magnitude of the early old/new effect, the putative ERP correlate of familiarity-based recognition memory.

How could this correlation be explained? As mentioned earlier, the N400 represents the access to semantic long-term memory and the extensive activation of a concept during semantic integration. The early old/new effect, however, is assumed to reflect the facilitated access to conceptual and perceptual information related to the test word as a function of a prior encounter of the word. The assumed memory process reflected in this effect enables the discrimination between old and new items but does not support a further differentiation between studied items and perceptually or semantically similar lures, for example [9,13]. By providing strongly activated semantic features necessary for item-specific recognition, a large N400 to an item increases the likelihood of its later recognition based on familiarity. In other words, familiarity-based recognition of words that violated a sentence semantically at study seems to benefit from a strongly activated semantic representation during study. Hence, semantic integration problems during language comprehension reflected in the N400 and the familiarity aspect of recognition seem to rely at least partly on analogous operations.

Although surface recorded ERPs cannot accurately localize the neural mechanisms underlying both processes, intracranial ERPs and functional imaging studies [14,15] have yielded evidence that both processes rely at least partially on similar brain structures in the medial temporal lobes.

Even though our data support the view of a close functional relationship between the N400 and the early old/new effect, a variety of differences (for example topography [16] or the dependency on top-down processes [17,18]) can be observed. In addition, while an access to semantic memory representations reflected in the N400 is possible for potentially meaningful stimuli only, familiarity can arise from a global matching process between study and test items [19] on a purely perceptual level [20], on both a perceptual and conceptual level [13,21] and on a purely conceptual semantic level [22].

Why did old/new effects not occur in the syntactic violation and the correct condition, even though no performance differences between the three conditions were obtained? An explanation can be derived from the assumption that for verbs from syntactically incorrect and correct sentences a higher proportion of guess responses may have contributed to the old responses. The absence of the N400 to syntactic violations at study can be taken to reflect the fact that concept integration does not take place for words that are not syntactically licensed. This might have led to an insufficient encoding of the words' meaning owing to a lack of contextual integration effort. So, a higher proportion of guess responses may have contributed to the correct old responses at test in the syntax as compared with the semantic violation condition. Items presented in correct sentences during study require a somewhat different encoding of the words' meaning during contextual integration. This is reflected in a (small) N400 to those items that might be explained by the shortness of the correct sentences used in this study. It is well known that the amplitude of the N400 is dependent upon the length of the sentential context [2]. Furthermore, in the case of correct sentence endings, the small N400 is hypothesized to lead to a weaker encoding of word meaning as compared with the processing of semantically violating verbs.

Conclusion

This study reports a functional relationship between semantic integration processes and familiarity-based recognition, suggesting that the early old/new effect is modulated by the amount of prior item specific conceptual processing.

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