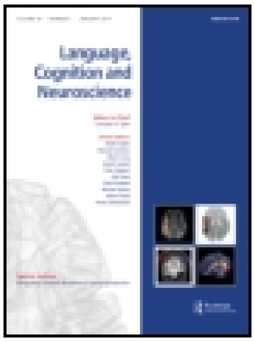

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REGULAR ARTICLE

Negation and the N400: investigating temporal aspects of negation integration using semantic and world-knowledge violations

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ABSTRACT
Negation comprehension is a time-consuming, resource demanding process. This study investigates whether additional time to process the negation operator eases negation integration. In Experiment 1 we analysed N400 amplitude in sentences of the following types: correct sentences (*Zebras are* (*not*) *stripy*), world-knowledge violation sentences (*Ladybirds are* (*not*) *stripy*) and semantically violated sentences (*Thoughts are* (*not*) *stripy*). In Experiment 2, the negation was pre-pended to the actual sentence using an introductory statement (*It is* (*not*) *true that ladybirds are stripy*) to provide additional processing time to deal with the negation operator. Crucially, in both experiments the N400 amplitude was larger for semantic and world-knowledge violations than correct sentences irrespective of the negation operator. Taken together, our study suggests that allowing additional time to process the negation operator alone – before encountering the information that completes the negated proposition – has no beneficial influence on on-line negation integration as reflected in the N400.

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Negation; N400; EEG; Semantic-Knowledge; World-Knowledge

Introduction

Negation comprehension is typically known to be an effortful process demanding cognitive resources (Deutsch, Kordts-Freudinger, Gawronski, & Strack, 2009). The literature suggests that negation implementation cannot be automatised even after extensive practice (Deutsch, Gawronski, & Strack, 2006; Dudschig & Kaup, 2018). However, there are specific conditions in natural language use – that is when negation is used in a way that allows predicting the upcoming sentence endings – when negation is as easy to process as its affirmative counterparts (Nieuwland, 2016; Nieuwland & Kuperberg, 2008). Interestingly, previous studies also showed that time plays a crucial role in the way negation is integrated and that additional processing time is required during negation comprehension in order to arrive at a correct representation of the sentence meaning (Kaup, Lüdtke, & Zwaan, 2006). In the current study, we investigate whether allowing more time for the negation to be incorporated into the comprehension process – by prepending the negation operator at the sentence beginning – modifies the way the meaning of the sentence is processed as indicated by the N400 component of the event-related brain potential (ERP).

Previous studies investigating negation integration often used N400 paradigms in order to analyse whether the negation operator – changing the truth-value of a sentence without changing its contents words – modifies the N400 complex. The N400 was first identified by Kutas and Hillyard (1980). It is a negative potential peaking around 400 ms over centro-parietal electrode sides associated with processing words or other meaningful information sources (e.g. sounds, pictures, signs etc.). The N400 is typically increased in situations where unexpected semantic information has to be processed, for example, in sentences ending with semantically unexpected words (e.g. *Mary ate the warm bread with socks.*). Various follow-up studies provided important insights into the parameters influencing the size of the N400 complex, such as word frequency (Kutas & Hillyard, 1984), word expectancy determined by cloze probability (Kutas & Federmeier, 2011), and semantic distance (Van Petten, 2014). In the decades following the first report of the N400 component, research regarding the N400 pursued two main goals. On the one side, questions with respect to the functional significance of the N400 complex were investigated – addressing, for example, whether the N400 reflects sentence-level integration or rather word-level association processes (for reviews see: Kutas & Federmeier, 2000; Lau, Phillips, & Poeppel, 2008). On the other side, N400 studies were

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used to draw conclusions with regard to specific language comprehension phenomena, for example, the question whether negation is initially integrated during the comprehension process. Currently, it is a widely accepted view that the N400 indeed allows measuring sentence-level and discourse integration effects, if the sentences evolve in a highly predictive manner or if the context is rather constraining (Hald, Steenbeek-Planting, & Hagoort, 2007; Nieuwland, 2016; Nieuwland & Martin, 2012; Nieuwland & Van Berkum, 2006). In the following, we will briefly summarise the insights N400 studies have provided with regard to negation integration.

Fischler, Bloom, Childers, Roucos, and Perry (1983) reported one of the first studies using the N400 to investigate negation comprehension with a sentence verification task. In this study, participants read sentences like "A carrot is (not) a vegetable (bird)", resulting in four conditions: true-affirmative (carrot-vegetable), true-negative (carrot-not-bird), false-affirmative (carrot-bird) and false-negative (carrot-not-vegetable). Hereby, the negation operator reverses the truth-value of the sentence without changing any of the content words of the sentence. Participants indicated whether the statements were true or false. The results showed that a mismatch between the subject- and the object-term of the sentence determines the N400 size, showing a particularly large N400 for false-affirmative (carrot-bird) and true-negative sentences (carrot-not-bird). It was concluded that the N400 effect reflects the semantic mismatch on the content word-level at a preliminary stage of sentence comprehension rather than an effect of a sentence's truth-value. Additionally, with regard to accounts of negation processing, the authors took their N400 results to suggest that first the proposition to-be-negated is understood before the negation itself is dealt with, following the tradition of a two-step model of negation integration (e.g. Clark & Clark, 1972). In a related study, Kounios and Holcomb (1992) showed no effect of the negation integration on the N400 complex, again suggesting that the sentence's truth-value is not the determining factor regarding N400 amplitude size.

Probably one of the most influential studies investigating negation integration and the N400 was conducted by Nieuwland and Kuperberg (2008). In their study, the authors argue that the ease of uttering and comprehending everyday language – including negation (e.g. Horn, 1989) – is in direct contrast to the difficulties typically reported for negation integration and suggest that the reported difficulties are probably due to the fact that in psycholinguistic studies negation is typically investigated in situations where negation use is not pragmatically licensed. The authors directly compared sentences that licensed negation use (e.g. "With proper equipment, scuba diving isn't very dangerous") versus under-informative statements (e.g. "Bulletproof vests aren't very dangerous") and showed that for pragmatically licensed negations, the negation becomes as easy to process and integrate as the affirmative information. In a very recent study, Schiller et al. (2017) showed that in pragmatically licensed contexts even the use of double negation becomes as easy or easier to integrate than its affirmative counterpart.

Interestingly, beyond the specific linguistic use of negation – whether it is pragmatically licensed or not – it has been shown that time plays a crucial role with regard to negation integration. For example, in a study by Kaup et al. (2006) it was investigated whether during negation comprehension participants typically first represent the counterfactual and subsequently the actual state of affairs. They used sentences such as "The door is not open" and subsequently presented pictures that either displayed the factual (closed door), the counterfactual state of affairs (open door), or an unrelated item. The results showed that only if sufficient time was provided between the sentence and the picture, participants responded faster to the picture matching the actual situation (i.e. closed door). Another study pointing to the time-requirements of negation integration was reported by Lüdtke, Friedrich, De Filippis, and Kaup (2008). In this study, participants performed a sentence-picture verification task: Participants read sentences (e.g. "In the front of the tower there is a / no ghost") and subsequently saw a picture of a matching or mismatching situation. The results showed that the N400 effects during picture processing were modified by the match between the sentence and the picture if there was sufficient time to process the sentential negation (1500 ms) but not in short stimulus-onset-asynchrony (SOA) conditions (300 ms). Again, these results were interpreted as showing that negation can be integrated to a level that the actual state of affairs is represented, however only if there is sufficient time for the negation to be processed (cf. Dudschig, de la Vega, & Kaup, 2015). Ferguson, Sanford, and Leuthold (2008) investigated the influence of a negation used in a context preceding a world-knowledge violation on ERP and eye-tracking tracking measures. Their eye-tracking results further supported the idea that negation is eventually incorporated into the comprehension process, however, only if there is sufficient processing time available during reading. Herbert and Kübler (2011) arrived at a similar conclusion in their EEG study and suggested that negation integration is a time- and resource-demanding cognitive process. Recently, Herbert and

Kissler (2014) suggested that task-factors and inter-individual differences also play a crucial role with regard to the question whether automatic and early negation integration can be observed.

Critically, none of the studies reported above investigated the effect of the temporal distance between the negation operator itself and the to-be-negated information within the sentence. In contrast, these studies exclusively focused on separating, for example, a pictorial stimulus from the negated sentence (e.g. Kaup et al., 2006; Lüdtke et al., 2008) or early versus late measurements within their dependent variable (e.g. within the ERP). In the current study, we aimed at investigating whether moving the negation operator itself to an earlier position within a sentence influences the negation integration process. In order to do so, we used sentences that in their affirmative version were either correct (e.g. *Zebras are stripy*), contained a world-knowledge violation (e.g. *Ladybirds are stripy*), or a semantic violation (e.g. *Thoughts are stripy*) (see also Dudschig, Maienborn, & Kaup, 2016a; Hagoort, Hald, Bastiaansen, & Petersson, 2004). The negation operator is an ideal way to manipulate sentence meaning without changing the lexical associations triggered by the content words in the sentence. Interestingly, whereas the world-knowledge violations render true by the use of negation (e.g. *Ladybirds are not stripy*), the semantic violations still remain violated or at least nonsensical (e.g. *Thoughts are not stripy*) and the correct sentences state false information if negated (e.g. *Zebras are not stripy*). By using these two types of violations, we hope to gain additional insights into whether the language comprehension system deals differently with fully nonsensical information (semantic violation) compared to pragmatically infelicitous, but correct information (negated world-knowledge violation). In Experiment 1, we aimed at replicating the standard effects typically reported during N400 processing for negation comprehension (i.e. no modification by the negation operator of effects reflecting associations between content words), with the extension that we differentiate between negation applied to world-knowledge and semantic violation conditions. In Experiment 2, we targeted the key question regarding the influence of timing on negation comprehension by using the sentences from Experiment 1 but this time allowing more time for processing the negation operator by moving it to the start of the sentence (e.g. *It is* (*not*) *true that zebras / ladybirds / thoughts are stripy*). If additional time to deal with the negation operator itself is sufficient to incrementally take into account the negation during sentence comprehension, we predict that shifting the negation operator to an earlier position in the sentence would result in N400 modifications by negating previously correct or false statements. If – in contrast – purely allowing more time to deal with the negation operator itself does not ease incremental negation integration, we expect that the N400 complex does not change by the use of a negation and the N400 patterns should resemble those in the affirmative condition (determined by noun-adjective lexical associations, see Dudschig, Maienborn, & Kaup, 2016b).

Importantly, then, the current study focuses on the question whether prepending the negation operator to the start of the sentence allows preparation for dealing with the subsequent to-be-negated information. Thus, in contrast to previous studies, this study purely extends the time to process the negation operator itself rather than the time the reader has to deal with the negated proposition as a whole. Thus, in two experiments we address the question whether the cognitive system can prepare for negating if it has sufficient time to deal with the negation operator itself. On the one hand, it is possible that additional time only helps the comprehender after the to-be-negated information has already been processed. In this case, independent of the position of the negation operator, there should be no difference in N400 amplitude for affirmative versus negative sentences. On the other hand, it is also possible that the cognitive system can initiate some type of preparation for differentially dealing with upcoming (correct or incorrect) information after having processed the negation-operator even if the negated proposition is not yet complete. For example, it is conceivable that the cognitive system upon encountering the negation operator prepares for incoming information that in an affirmative sentence would be unexpected, for instance, being prepared for reading "small" after having processed a sentence fragment such as "It is not the case that the elephant is … ". Such preparation effects are well documented in research on non-linguistic cognition, with preparation effects in task switching providing one prominent example (e.g. Meiran & Daichman, 2005).

Experiment 1

Method

Participants

Thirty right-handed German native speakers were tested (M_{age} = 22.13 years, SD_{age} = 4.07, 20 females). Two participants were excluded from the reported analysis due to removal of a large number of trials (>40%) following artefact correction, resulting in a final sample of 28 participants (M_{age} = 22.25 years, SD_{age} = 4.19, 18 females). Participants signed informed consent, were naive as to the purpose of the experiment, and were reimbursed by course credit or payment at the rate of 8 €/hour.

Stimuli

Overall 660 sentences were constructed for this experiment, including the original sentences used in Dudschig et al. (2016a, 2016b). These consisted of 504 experimental sentences and 156 filler sentences. Sixty-three of the filler sentences were constructed in line with the experimental sentences containing all six types of experimental condition (correct, world-knowledge and semantic both in affirmative and negated versions; see Table 1). These sentences were followed by comprehension questions. The remaining filler sentences were all correct sentences (e.g. "Donkeys are grey"). Each participant saw all filler sentences but only half of the experimental sentences (252), as these consisted of an affirmative and a negated version each. Across participants, it was ensured that each sentence occurred equally often in the negated and the affirmative condition. The 252 critical sentences split into 84 sentences for each violation condition (correct, world-knowledge and semantic). Of these 84 sentences per violation condition within a participant half were presented in the negated and the other half in the affirmative version. Across participants the random selection of affirmative and negated version of item was counterbalanced. The critical adjectives were identical across the three sentential conditions (e.g. *Zebras / ladybirds / thoughts are stripy*). As the negation condition would typically consist of one additional word between the noun and the adjective (i.e. the negation particle), we used various discourse particles in the affirmative condition to avoid this issue (e.g. *actually*, *indeed*, etc.). Example material can be found in Appendix A.

Procedure

The experimental procedure was controlled using Matlab (Psychtoolbox-3; Kleiner et al., 2007). Each trial started with a 1500 ms fixation-cross, presented in the centre of the screen. Stimuli were presented in black on a grey background. Each word was presented centrally for 300 ms followed by a 300 ms blank screen. After the final word, a 1000 ms blank screen was implemented. The experiment was split into three blocks (136 trials each), whereby it was ensured that sentence endings did not repeat within a block. In 15.44% of the trials, the sentences were followed by a comprehension question. This however was only the case for filler items. These filler items followed by comprehension questions were randomly distributed across the three blocks (range block 1: 15–27, range block 2: 16–29, range block 3: 17–27). Participants had to answer a yes-no question with regard to the previously read sentence (e.g. Filler: *Bakers sell typically bread*. Question: *Can bread typically be bought at the baker*?). It was ensured that comprehension questions were used across both affirmative and negated filler sentences, and across both correct and violated filler sentences. To successfully answer the comprehension question participants typically would need to integrate sentence meaning rather than rely on word based resonance.

EEG recordings and analysis

EEG was recorded using a BIOSEMI active electrode system at 70 Ag–AgCl electrode sides (midline: Fpz, AFz, Fz, FCz, Cz, CPz, Pz, POz, Oz, and Iz; left hemisphere: IO1, Fp1, AF3, AF7, F1, F3, F5, F7, F9, FC1, FC3, FC5, FT7, C1, C3, C5, M1, T7, CP1, CP3, CP5, TP7, P1, P3, P5, P7, O9, PO3, PO7, O1; and over the homologue electrode sides on the right hemisphere). The sampling rate for the EEG and electrooculogram (EOG) recordings was 512 Hz. EEG analysis was conducted using available MATLAB toolboxes (EEGLAB and FieldTrip; Delorme & Makeig, 2004 and Oostenveld, Fries, Maris, & Schoffelen, 2011, respectively) and custom MATLAB scripts (for details see: Dudschig, Mackenzie, Leuthold, & Kaup, 2018; Dudschig, Mackenzie, Strozyk, Kaup, & Leuthold, 2016). Vertical electroocular (vEOG) and horizontal EOG (hEOG) waveforms were calculated offline as follows: vEOG(t) = Fp1(t) minus IO1(t) and hEOG(t) = F9(t) minus F10(t). All EEG channels were recalculated to an average reference and high-pass filtered (0.1 Hz, 12 dB/octave). EEG data pre-processing was conducted for the analysis epoch from −500 to 1500 ms relative to the onset of the critical word. Analysis steps[1] included removal of eye-blink unrelated artefacts and correction of eye-blink artefacts, interpolation of removed data, and averaging of ERP data. Approximately 88% of trials remained in the analysis following artefact rejection. An average of approximately 3.5 ICA components per participant were removed. An average of approximately 1 electrode per participant was interpolated. The remaining trials were averaged, re-calculated to an average mastoid reference, and low-pass filtered (30 Hz, two-pass 36 dB/octave).

Statistical analysis and design

The mean ERP data averages across nine electrode positions (C1, Cz, C2, CP1, CPz, CP2, P1, Pz, P2) in the N400 time-interval (350–450 ms) with a 100 ms baseline before the onset of the critical word was submitted to a 3 × 2 repeated-measures ANOVA with the factors violation type (correct, world-knowledge, semantic) and polarity (affirmation versus negation). Where appropriate, Greenhouse-Geisser corrected *p*-values are reported.

For post-hoc *F*-tests, the significance level was Bonferroni corrected.

Results and discussion

Mean accuracy to the comprehension questions was high (>85%). The ANOVA of mean N400 amplitude (see Figure 1) revealed a main effect of violation type, $F(2, 54) = 19.18$, $p < .001$, $\eta_p^2 = 0.42$, $\varepsilon = 0.84$ (correct = −1.21 µV, semantic = −2.98 µV, world-knowledge = −2.54 µV). Post-hoc *F*-tests showed that the correct condition differed significantly from the semantic violation ($F(1, 27) = 24.94$, $p < .001$, $\eta_p^2 = 0.48$) and from the world-knowledge violation condition ($F(1, 27) = 21.99$, $p < .001$, $\eta_p^2 = 0.45$). The difference between the world-knowledge and the semantic violation condition was not significant, $F(1, 27) = 3.31$, $p = .08$, $\eta_p^2 = 0.11$. These N400 amplitude effects directly replicate previous findings regarding the effects of comprehending semantic and world-knowledge violations (e.g. Hagoort et al., 2004). There was no main effect of polarity, $F(1, 27) = 1.46$, $p = .24$, and most importantly for the purpose of the current study, there was also no interaction between violation condition and polarity, $F(2, 54) = 1.09$, $p = .34$, $\varepsilon = 0.83$, suggesting that negation did not modify the N400 amplitude pattern. In contrast, the association between the noun-adjective pair alone seems to determine the N400 size.

Experiment 2

Experiment 2 was designed to investigate the temporal dynamics of negation integration. If additional processing time is needed for negation integration, we expect that prepending negation to the start of the sentence should result in a modification of the N400 effect. In contrast, if indeed other factors are crucial for an early, successful negation integration – for example, pragmatically licensed use of negation – we expect to replicate the effects from Experiment 1.

Method

Participants

Thirty-two right-handed German native speaking participants were tested ($M_{age} = 23.28$, $SD_{age} = 3.36$, 27 females). One participant was excluded due to the removal of a large number of trials following artefact rejection (>40%) combined with poor performance in the comprehension questions (<20% correct), resulting in a final sample of 31 participants ($M_{age} = 23.29$, $SD_{age} = 3.42$, 26 females). Participants were naive as to the purpose of the experiment, and were reimbursed by course credit or payment at the rate of 8 €/hour.

Stimuli

The identical basic sentences as in Experiment 1 were used. This time the negation was moved to the beginning of the sentence by starting the sentence with one of the four following statements: *Es stimmt* (*nicht*), *dass*, … (It is (not) true that …) / *Es ist* (*nicht*) *so*, *dass* … (It is (not) the case that …) / *Es ist* (*nicht*) *richtig*, *dass* … (It is (not) correct that …) / *Es ist* (*nicht*) *wahr*, *dass* … (It is (not) true that …). Stimuli assignment followed a similar procedure to that of Experiment 1, resulting in 84 experimental items per violation condition for each participant with half of them in the affirmative and the other half in the negated version, counterbalanced across participants. Additionally, it was ensured that each type of sentence preface occurred equally often for the different violation conditions in both the affirmative and the negated version.

Procedure, EEG recordings, and statistical analysis

The procedure, all aspects of EEG recording and preprocessing, as well as N400 amplitude analysis were identical to Experiment 1. The filler items followed by comprehension questions were again randomly distributed across the three blocks (range block 1: 17–27, range block 2: 17–26, range block 3: 14–26). Approximately 85% of trials remained following artefact rejection. An average of approximately 3 ICA components per participant were removed. An average of approximately 1.5 electrodes per participant were interpolated.

Results

Mean accuracy to the comprehension questions was high (>90%). The ANOVA of the N400 mean amplitude (see Figure 2) showed a main effect of violation type, $F(2, 60) = 21.24$, $p < .001$, $\eta_p^2 = 0.41$, $\varepsilon = 0.94$ (correct = −0.86 µV, semantic = −3.32 µV, world-knowledge = −2.41 µV). Post-hoc tests indicated that the correct condition differed significantly from the semantic violation ($F(1, 30) = 33.28$, $p < .001$, $\eta_p^2 = 0.53$) and from the world-knowledge violation condition ($F(1, 30) = 17.87$, $p < .001$, $\eta_p^2 = 0.37$). The difference between the world-knowledge and the semantic violation condition was also significant, $F(1, 30) = 6.83$, $p = .014$, $\eta_p^2 = 0.19$. There was no main effect of polarity, $F(1, 30) = 0.54$, $p = .54$, and most importantly for the purpose of the current study, there was also no interaction between violation condition and polarity, $F(2, 60) = 1.18$, $p = .31$, $\varepsilon = 0.99$.

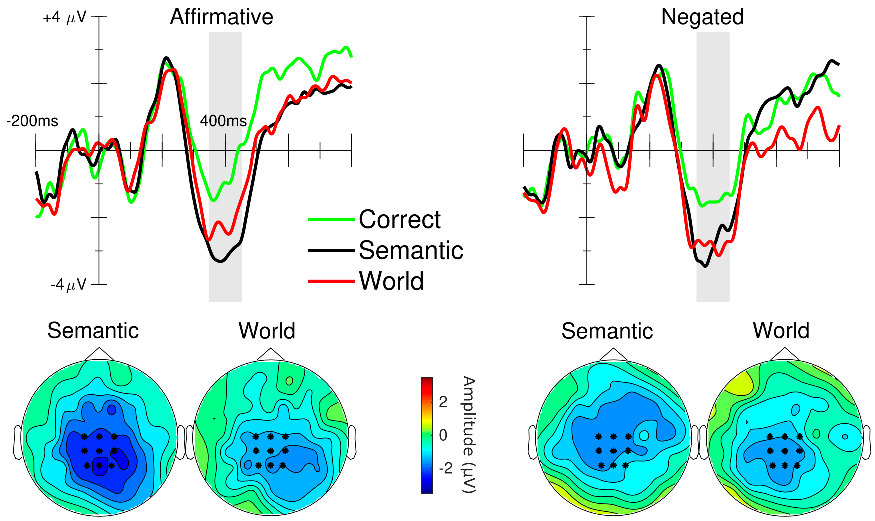

Figure 1. ERP waveforms (top plots) and topographic distribution (bottom plots) as a function of the experimental conditions (left: affirmative, right: negated). Difference topographies are calculated between the correct and the semantic-violation condition, and the correct and the world-knowledge violation condition, respectively.

This suggests that purely giving participants additional time to process the negation does not result in a modification of the N400 amplitude pattern. In contrast, again the association between the noun-adjective pair alone seems to determine the N400 size.

Additional analyses

Our study was designed to investigate whether the sentence-level meaning differences introduced by a negation operator are reflected in the N400 time window. The findings of two experiments suggest that that is not the case, even if the negation operator is shifted forward in a sentence – therefore providing additional time to process the operator. However, as our main result therefore is a null-effect we conducted several post-hoc analyses for two reasons (1) to show that our null-effects are meaningful and not the results of missing power and (2) to see whether there are other effects of negation that might be of potential interest for future research. With regard to the power issue the data were also examined by implementing a Bayesian approach (see Dienes, 2014; Wagenmakers et al., 2018), comparing the probability of the observed data under both the model with only condition and the model with condition, polarity and their interaction. The estimated Bayes Factor (BF) was calculated using the R-Package BayesFactor with the function anovaBF

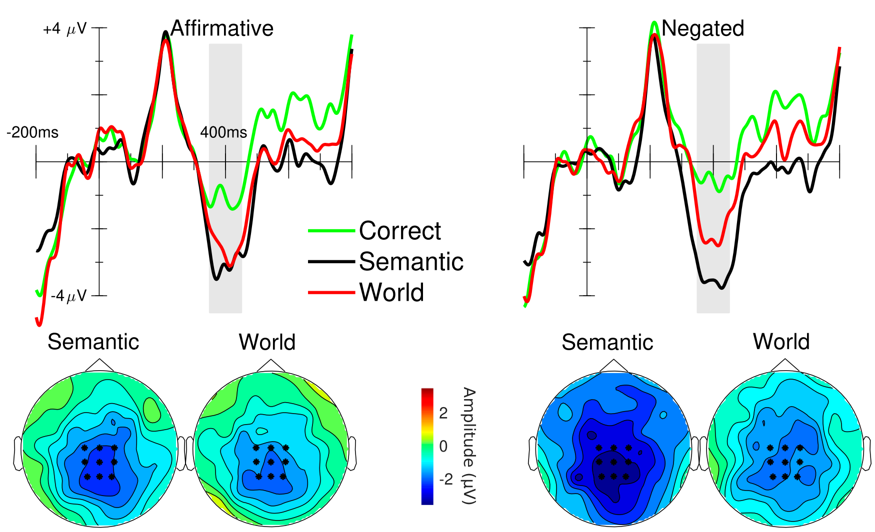

Figure 2. ERP waveforms (top plots) and topographic distribution (bottom plots) as a function of the experimental conditions (left: affirmative, right: negated). Difference topographies are calculated between the correct and the semantic violation conditions, and between the correct and the world-knowledge violation condition, respectively.

(Rouder, Morey, Speckman, & Province, 2012). For Experiment 1, the estimated BF was 0.09, meaning that the data pattern was approximately 11 times more likely under a model with condition only. For Experiment 2, the estimated BF was 0.04, meaning that the data pattern was approximately 25 times more likely under a model with condition only. After combining the data from Experiments 1 and 2, the estimated BF for the model including condition, polarity and their interaction was 0.007, showing that the data pattern was ~143 times more likely under a model with condition only. Thus, according to Wagenmakers et al. (2018) our results indicate strong evidence supporting the null interaction between condition and polarity, suggesting that negation integration in such contexts is not reflected in the N400 amplitude.

With regard to question (2) whether our data does show effects of negation (that were not part of the hypotheses) we conducted additional topographic analyses to check whether there were any distributional effects (see Figure 3 for topographic analysis setup). For both experiments we performed an ANOVA with the factors violation-type (correct, world-knowledge, semantic), polarity (affirmative, negated), and the additional topographic factors antpos (anterior, posterior) and hemisphere (left, middle, right). For neither experiment this analysis showed a main effect or interaction of any factor with the factor negation. Only in Experiment 1 there was a significant four-way interaction between polarity, violation-type, antpos and hemisphere ($F(4,108) = 3.53$, $p < .05$). However, this interaction did not replicate in Experiment 2 and we therefore most likely consider it as a Type I error of multiple testing. Finally, we performed cluster-based permutation tests in order to check whether other time intervals – outside the N400 range – showed an effect of negation. The permutation tests were performed with the standard constraint that at least two adjacent channels show a significant effect (see Maris & Oostenveld, 2007). These Montecarlo cluster-based permutation tests ($N = 1000$) are designed to deal with multiple comparisons. In order to have straightforward comparisons we decided to compare the difference between the correct and the world-knowledge condition between the affirmative and negated sentence (separately for Experiment 1 and 2). We chose this comparison as our main hypotheses were based on these two conditions, suggesting that full negation integration should result in a reversed

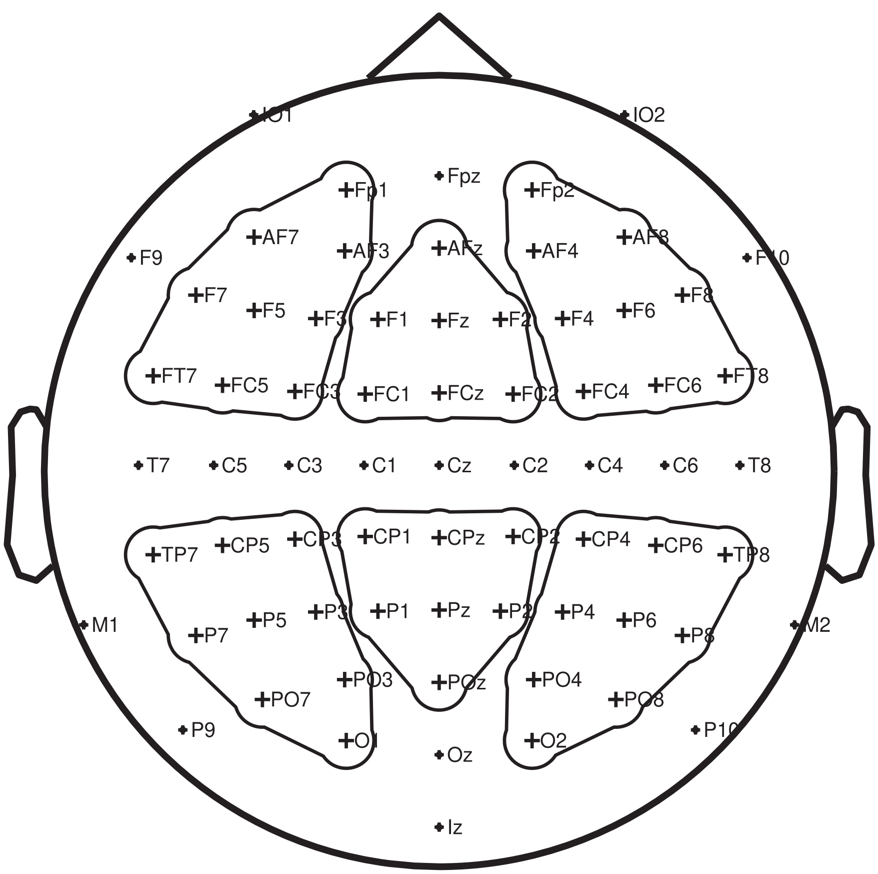

Figure 3. Electrode layout with highlighted regions of interest.

pattern of the correct ("Zebras are (not) stripy") and the world-knowledge ("Ladybirds are (not) stripy") condition in the affirmative and negated case. Again, these comparisons conducted in the time-window from 0 to 1 s did not show any significant effect, suggesting that there was no influence of negation.

General discussion

Negation comprehension is typically regarded as an effortful time-consuming process that demands cognitive resources. However, it has been argued that under special circumstances negation processing becomes as easy as processing affirmative statements. First, it has been shown that if negation is used in contexts where it is pragmatically licensed it is incrementally integrated to a level that the N400 reflects negation integration (e.g. Nieuwland, 2016; Nieuwland & Kuperberg, 2008). Second, it has been suggested that with sufficient time, negation integration takes place to a level that comprehension results in the representation of the negated information (e.g. Kaup et al., 2006). Critically, the factor of time has – to our knowledge – never been investigated with regard to the position of the negation operator within a sentence. With more time available after encountering the negation operator during reading, the cognitive system might be prepared for the forthcoming information and the integration of the negation might become easier and hence influence the N400. This is the key question addressed in the current study: We specifically aimed at investigating whether an early position of the negation operator in a sentence allows the comprehender to prepare processing in such a way that the negation can be instantly integrated once encountering the critical word that completes the negated proposition. If so, this should be reflected in N400 amplitude modifications at the time point of the occurrence of the critical word in conditions with an early position of the negation operator.

In the current study, this question was addressed by means of two experiments. In both experiments, correct sentences and sentences violated with regard to the world-knowledge or semantically violated sentences were used (see Dudschig et al., 2016a, 2016b; Hagoort et al., 2004). By using negation, the correct sentences turned into statements that expressed false information (e.g. *Zebras are not stripy*). In contrast, sentences violated with regard to world-knowledge rendered true by the use of negation (e.g. *Ladybirds are not stripy*). The third sentence type – namely semantically violated sentences – stayed rather nonsensical even after the introduction of the negation operator (e.g. *Thoughts are not stripy*). Both ERP experiments showed that negation integration – even with additional time as provided in Experiment 2 – does not advance to a level that the N400 effect would be modified. Thus, sentences that express wrong information (e.g. *It is not true that zebras are stripy*) result in identical N400 amplitudes as their correct – affirmative – counterpart (e.g. *It is true that zebras are stripy*). Our results thereby suggest that additional time to process the negation operator itself is not sufficient for incremental negation integration within such a context.

How do our results then relate to those reported by earlier studies coherently suggesting that with additional time, negation integration can be handled rather completely (e.g. Kaup et al., 2006; Lüdtke et al., 2008)? As mentioned above, there are several important differences between our and these earlier studies. Most importantly, in the current study, the negation operator itself was moved forward with regard to its position in the sentence so that participants had ample time to process the negation operator itself before encountering the information in the scope of the negation. In principle, this should give participants time to prepare for applying the negation to the information in its scope. In contrast, earlier studies investigating negation integration typically manipulated the SOA between the sentence and a subsequent task that aimed to uncover the content of the meaning representations currently available to the reader. For example, several studies have manipulated the time between a full negated statement and a matching or mismatching picture (e.g. Kaup et al., 2006). Thus, in contrast to earlier studies, we did not increase the time to deal with the negated proposition itself after having read it in full, but rather the time to deal with the negation operator during the ongoing processing of further linguistic input. Interestingly, there are studies suggesting that the negation operator itself has an influence on comprehension processes, for example, by triggering inhibitory tendencies (e.g. Aravena et al., 2012; de Vega et al., 2016). However, our results showed that prepending the negation operator to an early position in the sentence does not allow the comprehender to prepare to a level that allows incremental integration of upcoming information with regard to its truth-value (in a manner that it would influence N400 amplitude). In contrast, our findings suggest that even when the negation operator is moved forward, the comprehension process first evolves in the standard manner as reported in other N400 studies using negation in pragmatically un-licensed statements (e.g. Fischler et al., 1983).

To our knowledge, our study is the first in addressing the difference between negating world-knowledge versus semantic violations. The question whether the processing system differentiates between these two kinds of violations is particularly relevant for distinguishing between so-called one- versus two-step models of comprehension (e.g. Hagoort et al., 2004; see also Dudschig et al., 2016a, 2016b). Our results suggest that N400 amplitudes are not reduced in the case where negation renders a formerly violated statement true (as is the case for negated word-knowledge violations) compared to a case in which the statement stays semantically violated even after negation integration (as is the case for negated semantic violations). In other words, the negation in our study did not reverse the pattern of N400 amplitudes for any of the two different kinds of violations, a result that would have been expected for the world-knowledge violation if N400 amplitudes reflected fully-fledged sentence-based integration processes including a successful on-line integration of the negation marker. The results of the current study indeed suggest that at the time point where the N400 is measured the full sentence-level meaning is not always reflected in the N400 component. In contrast, previous studies suggest that only if the sentences evolve in a pragmatically licensed – and therefore predictable – manner, incremental interpretation of sentence-level meaning takes place instantly and is reflected in the N400 amplitude (e.g. Nieuwland, 2016).

Another question that needs to be addressed is the following: Does our result suggest that participants do not process negation? No, our results cannot distinguish between the possibility that participants have indeed processed negation but that this is not reflected in the N400 time-window, or that negation is not processed to a sentence-integration level by this time-point. Nevertheless, our study shows that the N400 marker does not reflect sentence-level processes under all circumstances even in a situation where participants should have enough time to realise that they are dealing with a negated sentence. Our results leave open the question whether another dependent variable might reflect negation integration processes during on-line sentence comprehension.

In summary, the current study provides important insights with regard to negation comprehension during online sentence comprehension. In contrast to previous studies suggesting that with sufficient time negation integration becomes easier, our study suggests that this does not apply if the additional time is provided to deal with the negation operator itself. In contrast, additional time seems to help only if this additional time is provided after both the negation operator and the to be negated proposition has been made available to the comprehender (see Kaup et al., 2006). Thus, with regard to online language comprehension, the current study supports models suggesting that the predictability of words in certain contexts might ease the way complex linguistic phenomena – such as negation – are dealt with. However, basic factors such as additional time do not seem to result in changes of predictions and therefore do not seem to influence the N400 complex.

Note

1. Specifically, a predefined *z*-score threshold of ±3 was used to identify outliers relating to channels, epochs, independent components, and single-channels in single-epochs. After removing epochs containing extreme values in single electrodes (e.g. amplifier blockings, values larger ±500 μV in any electrode) and trials containing values exceeding ±75 μV in multiple adjacent electrodes unrelated to eye movements, *z*-scored variance measures were calculated for all electrodes. Noisy EEG electrodes (z-score > ±3) were removed if their activity was uncorrelated to EOG activity and this "cleaned" EEG data set was subjected to a spatial independent components analysis (ICA) based on the infomax algorithm (Bell & Sejnowski, 1995). ICA components representing ocular activity (blinks and horizontal eye movements) were automatically identified using *z*-scored measures of the absolute correlation between the ICA component and the recorded hEOG and vEOG activity, respectively, and confirmed by visual inspection. Then, previously removed noisy channels were interpolated in the ICA-cleaned EEG data set using the average EEG activity of adjacent uncontaminated channels within a specified distance (4 cm, ~3–4 neighbours per electrode). This ensured a full electrode array for each participant.

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