Insensitivity to truth-value in negated sentences: does linear distance matter?

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Abstract. Affirmative sentences are comprehended more quickly when they are true vs. false but this facilitation is often reduced or absent in negative sentences, yielding a so-called negation-by-truth-value interaction. The reduced sensitivity to truth-value has been attributed to processing difficulties triggered by negation. We investigated whether such difficulties were eased when comprehenders were given more time to process the negator. Specifically, we compared negated sentences in which the negator immediately preceded an adjectival predicate vs. occurred earlier in the sentence, separated by several words from the predicate. The results of two sentence-picture matching tasks replicated previous findings of increased processing difficulties in negative vs. affirmative sentences, as well as the negation-by-truth-value interaction. However, we did not find evidence that sensitivity to truth-value was modulated by the distance between the negator and the predicate. Our findings suggest that, when sentences are presented in isolation, having more time to process a negator does not confer a measurable comprehension advantage.

Keywords. Negation; linear distance; truth-value; sentence-picture matching; comprehension; German

1. Introduction. Sentences are usually easier to process when they are true, but this generalization is challenged by negative sentences. This was shown in sentence-picture verification studies, in which participants saw pictures together with affirmative or negative sentences and indicated whether the pictures rendered the sentences true or false. The results showed that affirmative sentences were evaluated more quickly when they were true vs. false, but sensitivity to truth-value was often reduced—or even absent—in negative sentences, giving rise to a "negation-by-truth-value interaction" (for reviews see Kaup & Dudschig 2020; Carpenter & Just 1975).

Crucially, the negation-by-truth-value interaction was later replicated in tasks without a judgment/verification component, e.g., participants only had to decide whether a pictured object had been mentioned in the sentence (Kaup, Lüdtke & Zwaan 2005; Tian, Breheny & Ferguson 2010). These results suggested that the processing difficulty elicited by negation is a general marker of its comprehension, rather than a by-product of truth-value judgments. This motivated the claim that negative sentences are generally understood in two steps. For example, given the sentence "The package is not wrapped", comprehenders first represent the counterfactual (or alternate) state-of-affairs expressed by the affirmative proposition ('the package is wrapped'). Later, in a second step, this alternate representation is suppressed, and the actual state-of-affairs is

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represented (Kaup, Lüdtke & Zwaan 2005; Kaup, Lüdtke & Zwaan 2006). Because the activation of an alternate interpretation and its suppression are triggered by negative but not by affirmative sentences, 2-step models can explain why negation increases processing time. They can also explain the negation-by-truth-value interaction by proposing that comprehenders create mental simulations of the state-of-affairs described by a sentence. If the sentence is followed by a task to identify a pictured object, responses are faster when the picture matches the simulation created while reading the sentence, and slower when it mismatches this simulation. The lack of processing facilitation for true negative sentences occurs because, at the point of picture identification, the alternate state-of-affairs is still activated, which interferes with identification responses and neutralizes the processing advantage otherwise obtained with true statements.

However, later findings suggested that the representation of an alternate state-of-affairs could be diminished or even avoided altogether when negative sentences were pragmatically licensed by context and/or the question-under-discussion was prominent (Nieuwland & Kuperberg 2008; Orenes, Beltrán & Santamaría 2014; Tian, Breheny & Ferguson 2010; Tian, Ferguson & Breheny 2016; Darley, Kent & Kazanina 2020). For example, Tian et al. (2016) used the visual world eye-tracking paradigm to demonstrate that when the question-under-discussion was clear to comprehenders, they no longer activated a counterfactual interpretation in English negative sentences. In another visual world study, Orenes et al. (2014) showed that English participants could quickly switch their visual attention to the actual state-of-affairs after hearing a sentence like "The figure is not red", when an alternative interpretation was clearly available, e.g., through a visual context showing only red or green figures. Further, an event-related potentials study by Nieuwland & Kuperberg (2008) demonstrated that brain responses were sensitive to truth-value when negative sentences were preceded by a pragmatically licit linguistic context (e.g., "With proper equipment, scuba-diving isn't dangerous/*safe").

The findings above indicate that the activation of an alternate interpretation depends on the pragmatic licensing of a negated sentence. The open question is whether non-pragmatic factors may also play a role to help ease the comprehension of negation. One such factor concerns the distance between the negator and its predicate. For example, a negator may appear immediately before an adjectival predicate (as in the example above, "The package is not wrapped") or farther away, e.g., separated by several words: "It is not true that the package is wrapped". Increased distance might ease the processing of negation either by preventing the activation of an alternate interpretation and/or by facilitating its suppression when the adjectival predicate is encountered.

To date, only one study has examined this hypothesis but it found no evidence that processing differences were modulated by the linear position of the negator (Dudschig et al. 2019). The study used event-related potentials and measured brain responses to adjectives in true and false German sentences in which the negator occurred either immediately before an adjective or separated by several words, e.g., "Ladybirds are not stripy" vs. "It is not true that ladybirds are stripy" —note that the falseness of the sentences was based on world knowledge violations, e.g., about the typical pattern of ladybirds. For negative sentences like "Ladybirds are not stripy", the N400—a negative potential peaking around 400 milliseconds over centro-parietal brain regions—had been previously found to be insensitive to the sentence truth-value (Fischler et al. 1983). Dudschig et al. (2019) examined whether increasing the distance between the negator and the adjective would yield N400 sensitivity to truth value. The results showed that N400 responses at the adjective were similar in the close and far distance conditions, suggesting that more time to process the negator did not aid comprehension.

However, some methodological aspects make it difficult to directly compare the results of Dudschig et al. (2019) with those of previous sentence-picture matching studies (Kaup, Lüdtke & Zwaan 2005; Tian, Breheny & Ferguson 2010). In contrast to Dudschig et al. (2019), sentence-picture matching studies measured comprehension after the entire sentence was read and used response times—as opposed to brain responses to one word—as a processing diagnostic of the negation-by-truth-value interaction. To resolve these differences, we adopted the conditions of Dudschig et al. (2019) in a sentence-picture matching task in German. Like previous studies, we used an implicit version of the task: participants did not have to evaluate the sentences but rather whether a pictured object had been mentioned in the sentence.

We conducted two experiments. Experiment 1 replicated the negation-by-truth-value interaction reported in previous research by comparing affirmative and negative sentences—the negator in the negative versions immediately preceded the adjectival predicate. Experiment 2 compared negative sentences in which the negator was adjacent with the predicate vs. separated by several words, to examine whether more distance—and thus more processing time—would facilitate negation processing, either by preventing the activation of an alternate interpretation and/or by facilitating its suppression later on. If so, we expected to restore participants' sensitivity to truth-value in far distance negative sentences (but not in close distance sentences), yielding an interaction between truth-value and the distance between the negator and the predicate.

2. Methods.

2.1. MATERIALS. The critical sentences in Experiment 1 consisted of 40 item sets with the structure 'The noun is {here/not} adjectival predicate', e.g., "Das Paket ist hier/nicht eingepackt" (Table 1). All items had an affirmative and a negative version, with the negative version featuring the negator "nicht" linearly adjacent to the predicate (i.e., a close distance configuration). The affirmative sentences replaced the negator with the word "hier" ('here'), such that affirmative and negative sentences had the same number of words.

Each item set was paired with two pictures depicting either the actual or the alternate state-of-affairs described in the sentence (e.g., an image of a wrapped vs. an unwrapped package). The pictures were black-and-white drawings, either AI-generated (https://illustroke.com/) or collected from different sources on the web and manually edited if necessary. Both the picture and the adjectival predicate (e.g., "eingepackt" vs. "ausgepackt", 'wrapped' vs. 'unwrapped') were used to manipulate the state-of-affairs. These two factors were fully crossed to ensure that between-condition differences were not attributable to differences in the lexical properties of the predicates or in the visual complexity of the images. This resulted in eight Latin-square lists, which were collapsed to four in the analysis—since the individual effects of picture and predicate identity were not of theoretical interest for the current study. Thus, Experiment 1 had a Polarity (affirmative/negative) × State-of-affairs (actual/alternate) design.

Experiment 2 also featured 40 item sets. The (close distance) negative conditions in Experiment 1 were retained, but affirmative sentences were replaced by negative sentences in which the distance between the negator and the adjectival predicate was increased by moving the negator to a preceding clause (3 words away from the predicate), e.g., "Es stimmt nicht, dass das Paket eingepackt ist" ('It is not true that the package is wrapped'). The identity of the picture and of the predicate were fully crossed, resulting in 8 Latin-square lists—collapsed to four in the analysis. Thus, Experiment 2 featured only negative sentences in a Distance (close/far) × State-of-affairs (actual/alternate) design.

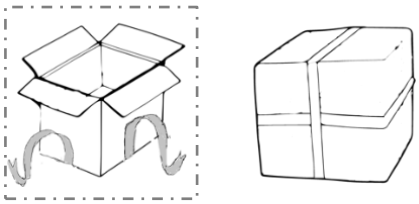
Experimental conditions	Pictures (one picture shown per trial)
a. **Affirmative, actual** Das Paket ist hier ausgepackt. 'The package is here unwrapped.'	
b. **Affirmative, alternate** Das Paket ist hier eingepackt. 'The package is here wrapped.'	
c. **Negative close distance, actual** Das Paket ist nicht eingepackt. 'The package is not wrapped.'	
d. **Negative close distance, alternate** Das Paket ist nicht ausgepackt. 'The package is not unwrapped.'	
e. **Negative far distance, actual** Es stimmt nicht, dass das Paket eingepackt ist. 'It is not true that the package is wrapped.'	
f. **Negative far distance, alternate** Es stimmt nicht, dass das Paket ausgepackt ist. 'It is not true that the packet is unwrapped.'	

Table 1: Sample item set in Experiments 1 and 2. Conditions (a–d) were used in Experiment 1. Conditions (c–f) were used in Experiment 2. The picture for the actual state-of-affairs is displayed with a dotted line for explanatory purposes only. In the alternative Latin-square lists (not shown here), the other image was the target picture, and the adjectival predicate was reversed.

2.2. PARTICIPANTS. The participants were self-reported first language speakers of German, who were recruited using the online platform Prolific (http://www.prolific.com/). We excluded participants who reported being left-handed, having uncorrected vision or language impairments, or who did not solve at least 80% of the attention checks presented during the experiment (see section 2.3). This resulted in a final sample of 69 participants in Experiment 1 (age range: 19–45 years; 29 women, 1 non-binary) and 72 in Experiment 2 (age range: 18–44 years; 35 women, 3 non-binary). The experiments were performed in accordance with the Declaration of Helsinki and the procedure was reviewed and approved by the Ethikkommission der Deutschen Gesellschaft für Sprachwissenschaft. All participants provided informed consent to participate in the study.

2.3. PROCEDURE. Participants completed the sentence-picture matching task online in the testing platform PCIbex (Zehr & Schwarz 2018). Sentences were shown word-by-word (SOA = 300 ms) and were followed by a picture. Participants were instructed to press a key for 'yes' when the object shown in the picture appeared in the sentence and 'no' when it did not appear. The F and J keys were used for this purpose—their mappings to 'yes' and 'no' were counterbalanced across participants. The target answer was always 'yes' for the experimental sentences. In Experiment 1, the picture appeared 400 ms after the sentence offset. In Experiment 2, the picture appeared 400 ms after the sentence offset in the close distance conditions, and 100 ms after the sentence offset in the far distance conditions. This ensured that the time elapsed between the presentation of the adjectival predicate and the picture was identical across the close and far distance conditions (i.e.,

400 ms). Thus, differences between conditions could not be attributed to participants having different amounts of time to plan their answers.

The experimental sentences were intermixed with 40 filler sentences. In Experiment 1, the filler sentences had the same structure as the experimental sentences but were always affirmative, e.g. “Die Brille ist jetzt geputzt” (‘The glasses are now cleaned’). To add lexical variation, the word “hier” in the experimental items was replaced with other one-syllable adverbs in the filler items, e.g., “jetzt”/“sehr”/“dort” (‘now’/‘very’/‘there’). All fillers had ‘no’ as a target answer such that ‘yes’ and ‘no’ target responses had a 1:1 ratio across the experiment. In Experiment 2, half of the fillers were adapted to start with a preamble comparable to that in the far distance negative sentences, e.g., “Es stimmt, dass die Brille jetzt geputzt ist” (‘It is true that the glasses now are cleaned’). Experimental and filler items were interspersed with 12 attention checks (Oppenheimer, Meyvis & Davidenko 2009). In the attention checks, the sentences were followed by comprehension questions instead of pictures, in order to encourage participants to understand the sentences (e.g., sentence: “The coffee is already cold”; question: “Has the coffee cooled down yet?”; response options: yes/no). After 4 practice items, the 92 trials (experimental items, fillers and attention checks) were presented in a randomized manner. An experimental session lasted 10–15 minutes.

2.4. ANALYSIS. Raw data were preprocessed manually in order to correct typos and inconsistent demographic responses. The preprocessed data was exported for analysis to R (R Development Core Team 2024). Following previous research (Kaup, Lüdtke & Zwaan 2005; Tian, Breheny & Ferguson 2010), the main dependent measure in the analysis was the response time in correctly answered trials. Following Kaup et al. (2005), we excluded trials with response times shorter than 200 ms or longer than 5000 ms (Experiment 1: 0.43–1.3% of trials across conditions; Experiment 2: 0.56–2.64% of trials across conditions). Following the Box-Cox procedure (Box & Cox 1964), response times were reciprocally transformed (–1000/response time). We also analyzed the accuracy of picture responses. Accurate responses were coded as 1 and inaccurate responses as 0.

Response times were analyzed with frequentist mixed-effects linear regression and accuracy was analyzed with mixed-effects logistic regression. In Experiment 1, the critical fixed effects were State-of-affairs (sum-coded, –0.5 actual/0.5 alternate), Polarity (sum-coded, –0.5 affirmative/0.5 negative) and their interaction. In Experiment 2, the critical fixed effects were State-of-affairs (sum-coded, –0.5 actual/0.5 alternate), Distance (sum-coded, –0.5 close/0.5 far) and their interaction. Trial Order was added as an additional (centered) fixed effect. Pairwise comparisons were performed using the *emmeans* package (Lenth 2017). The random structure of the models initially included intercepts and slopes for the critical fixed effects and their interaction. When a model failed to converge, its random effect structure was simplified following the recommendations in Barr et al. (2013). For the linear models, p-values were computed using Satterthwaite’s approximation for denominator degrees of freedom (Kuznetsova, Brockhoff & Christensen 2013).

3. Results. Experiment 1 replicated the finding of a reduced sensitivity to truth-value in negated sentences: response times were faster for pictures showing actual vs. alternate states in affirmative, but not in (close distance) negative sentences, resulting in a significant State-of-affairs×Polarity interaction (Table 2 and Figure 1). Response times were also faster for pictures following affirmative vs. negative sentences. The accuracy analysis showed fewer errors for pictures of actual than alternate states. This effect was significant in affirmative and negative sentences, but it was numerically smaller in negative sentences, consistent with the reduced truth-value sensitivity in response times.

Experiment 2 used the same close distance negated sentences as Experiment 1, but the affirmative sentences were replaced with negated sentences in which the negator had a farther linear distance from the adjectival predicate. Contrary to expectations, there was no evidence that sensitivity to truth-value was increased in the far distance negated sentences (i.e., non-significant State-of-affairs×Distance interaction in response times). Thus, we did not find that the distance between the negator and the predicate modulated sensitivity to truth-value in the response times of negative sentences. The response times only showed faster picture recognition times for close vs. far distance negated sentences. The accuracy analysis revealed fewer errors for pictures of actual vs. alternate states, but pairwise comparisons revealed that this effect was only significant in the close distance conditions—thus replicating the pattern seen with these sentences in Experiment 1.

	Response time				Accuracy			
	β	*SE*	*t*	*p*	*β*	*SE*	*z*	*p*
Experiment 1								
Intercept (grand mean)	–1.28	0.04	–29.58	<.001	3.40	0.23	14.58	<.001
Trial order	–0.00	0.00	–14.40	<.001	0.03	0.00	8.94	<.001
State-of-affairs	0.05	0.02	2.66	.011	–1.98	0.37	–5.32	<.001
Polarity	0.05	0.02	2.70	.010	0.22	0.23	0.98	.328
State-of-affairs×Polarity	–0.08	0.04	–2.40	.020	0.70	0.40	1.75	.080
SoA: aff. sentences	0.09	0.03	3.24	.002	–2.33	0.43	–5.51	<.001
SoA: neg. sentences	0.00	0.02	0.32	.746	–1.63	0.42	–3.85	<.001
Experiment 2								
Intercept (grand mean)	–1.22	0.05	–26.95	<.001	4.08	0.28	14.41	<.001
Trial order	–0.00	0.00	–15.33	<.001	0.02	0.00	5.57	<.001
State-of-affairs	0.00	0.02	–0.12	.907	–1.19	0.32	–3.78	<.001
Distance	0.06	0.02	3.82	<.001	0.08	0.20	0.39	.694
State-of-affairs×Distance	–0.01	0.03	–0.49	.625	1.13	0.43	2.63	.009
SoA: close distance	0.00	0.02	0.24	.809	–1.76	0.39	–4.54	<.001
SoA: far distance	–0.01	0.02	–0.42	.678	–0.23	0.38	–1.67	.094

Table 2: Results of the statistical analysis. Abbreviations: aff. = affirmative, neg. = negative, SoA = state-of-affairs. Estimates are expressed in reciprocal milliseconds for response time and log odds for accuracy.

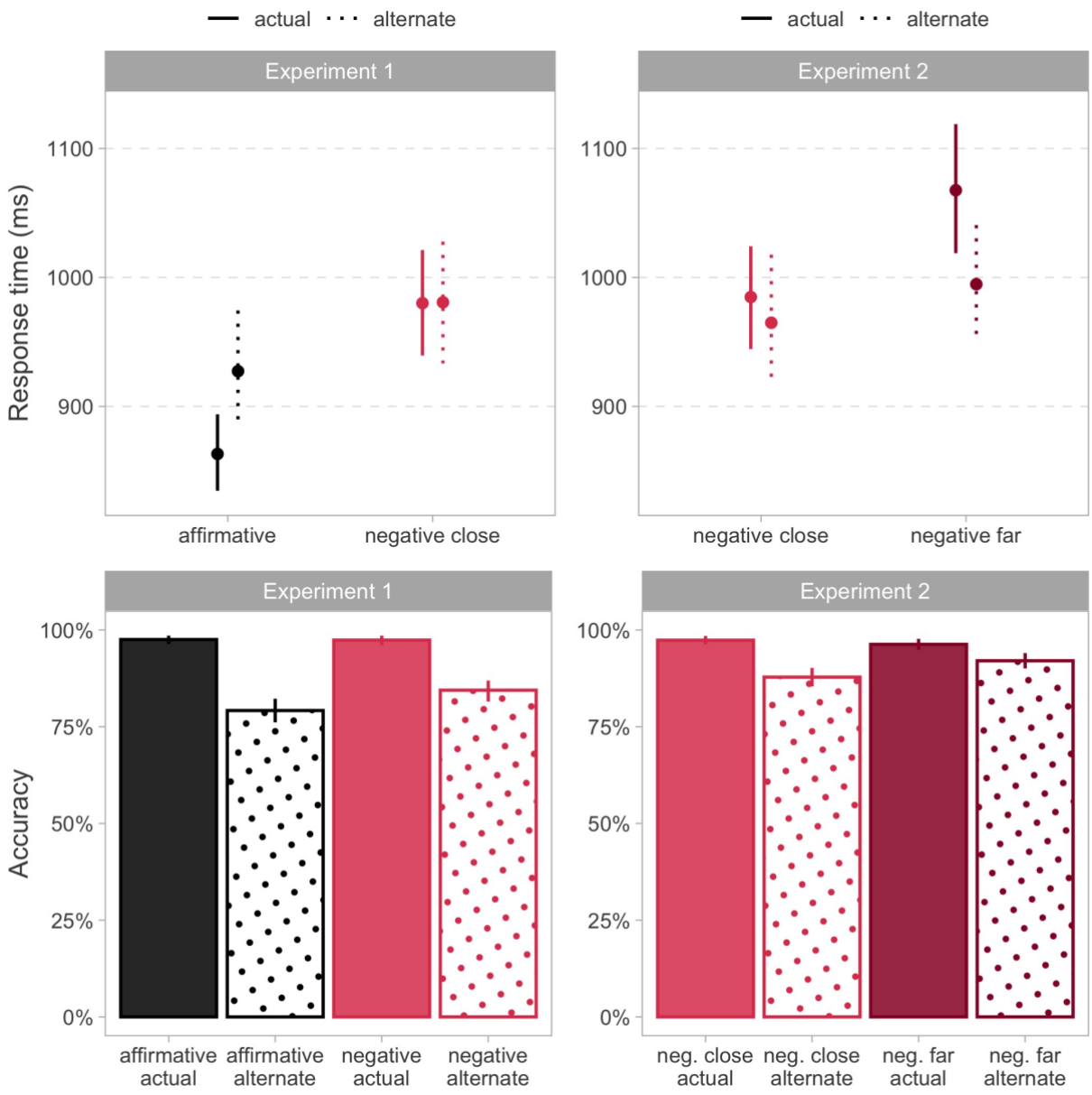


Figure 1: Descriptive summary of the response times of correct responses (top row) and accuracy (bottom row), averaged across items and participants. Error bars show 95% confidence intervals. Abbreviations: neg. = negative.

4. Discussion. We conducted two sentence-picture matching tasks to examine German speakers' sensitivity to truth-value in negative sentences, as well as its modulation by the linear position of the negator. The findings of Experiment 1 replicated the negation-by-truth-value interaction found in previous studies (Kaup, Lüdtke & Zwaan 2005; Tian, Breheny & Ferguson 2010). Specifically, participants were faster judging pictures that truthfully represented the state-of-affairs described by the sentence, but this processing facilitation disappeared in negative sentences. This does not mean that participants were blind to truth-value: they showed fewer errors with actual than alternate pictures in both affirmative and negative sentences, which shows that truth-value affected

their answers. Thus, the results of Experiment 1 demonstrate that true sentences elicit more accurate responses—even in a task that does not require truth judgments—but that difficulties related to comprehending negative sentences can neutralize the effect of truth-value in processing time.

Experiment 2 focused on negative sentences and compared structures in which the negator appeared linearly close to the adjectival predicate vs. earlier in the sentence, i.e., separated by several words (and a clause boundary) from the predicate. In close distance negated sentences, we found fewer errors for actual than alternate pictures but no evidence of truth-value sensitivity in response times, thus replicating Experiment 1. In long distance negative sentences there was no evidence of sensitivity to truth-value in either accuracy or response times. This fails to support the hypothesis that an early occurrence of the negator, which introduces more distance—and thus processing time—between the negator and the predicate, restores sensitivity to truth-value.

With regard to 2-stage accounts of negation, our findings suggest that having more time to process the negator does not prevent the creation of a counterfactual interpretation when the adjectival predicate is read, or its suppression to proceed to the creation of an actual interpretation. Previous findings indicated that the activation of a counterfactual interpretation depended on whether the linguistic and/or visual context made the actual and alternate interpretations similarly salient, or whether it introduced a question-under-discussion in which the truth of the affirmative counterpart was at issue (Nieuwland & Kuperberg 2008; Orenes, Beltrán & Santamaría 2014; Tian, Breheny & Ferguson 2010; Tian, Ferguson & Breheny 2016; Darley, Kent & Kazanina 2020). Our study adds to previous research by demonstrating that giving participants more time to process the negator does not, by itself, reduce the activation of a counterfactual interpretation, at least when the target sentences are presented in isolation. Our study conceptually replicates the event-related potential study of Dudschig et al. (2019), and it demonstrates similar results using a different type of dependent measure and task (response times in a sentence-picture matching task) and a design in which participants' decisions did not rely on detecting world knowledge violations.

Our study has some limitations, and it also leaves some open questions for future research. One limitation concerns the type of negation used in the far distance sentences, e.g., 'It is not true that…'. While the close distance sentences simply negated a specific state of affairs, the far distance sentences introduced a type of metalinguistic negation that is typically used to reject a previous assertion (e.g., 'The package is wrapped'). It is possible that this encouraged (rather than discouraged) the creation of a counterfactual affirmative interpretation and thus increased processing difficulty. This explanation would account for the finding that both long distance negative sentences elicited longer response times than the close distance sentences, consistent with higher processing effort. Future research could address this possibility by using a different structure to manipulate the distance between the negator and the relevant predicate.

An important open question concerns the potential relationship between the linear position of the negator and the pragmatic licensing of the sentence. Specifically, it remains to be tested if the position of the negator would play a role if negative sentences were pragmatically licensed, e.g., if they had been presented in context, as opposed to in isolation. A second open question concerns the crosslinguistic generalizability of our findings. Our target sentences were in German, a language in which sentential negation is located in a low fixed position (Zeijlstra 2004), but in which the linear position of the negator "nicht" is variable (Steube 2006; Sudhoff 2008). For example, "nicht" follows finite verbs in main clauses, but precedes the verbal complex in subordinate clauses. Moreover, definite determiner phrase objects and prepositional phrase adjuncts scramble across the negator, while other constituents do not (Frey & Pittner 1998). Given

the variable position of the negator, German comprehenders might adopt a conservative processing strategy and delay the interpretation of negation until the relevant predicate is encountered. Thus, the linear position of the negator might not be a reliable cue in the comprehension of negation in languages like German, in which the base and linear position of negation differ. Future research on languages in which the linear position of negation exhibits less variation (e.g., Spanish, Polish and Basque) as well as languages with early occurring, preverbal negation such as Spanish would be useful to address this possibility.

5. Supplementary materials. Data, analysis code and materials are publicly available at the Open Science Framework: https://osf.io/x9ue3/.

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