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The fate of the unexpected: Consequences of misprediction assessed using ERP repetition effects

Melinh K. Lai[a,b,*], **Joost Rommers**[d], **Kara D. Federmeier**[a,b,c]

[a]Department of Psychology, University of Illinois, Urbana-Champaign, USA

[b]Beckman Institute for Advanced Science and Technology, University of Illinois. Urbana-Champaign, USA

[c]Program in Neuroscience, University of Illinois, Urbana-Champaign, USA

[d]School of Psychology, University of Aberdeen, Aberdeen, Scotland, UK

Abstract

Amid increasing interest in the role of prediction in language comprehension, there remains a gap in our understanding of what happens when predictions are disconfirmed. Are unexpected words harder to process and encode because of interference from the original prediction? Or, because of their relevance for learning, do expectation violations strengthen the representations of unexpected words? In two experiments, we used event-related potentials to probe the downstream consequences of prediction violations. Critical words were unexpected but plausible completions of either strongly constraining sentences, wherein they constituted a prediction violation, or weakly constraining sentences that did not afford a clear prediction. Three sentences later the critical word was repeated at the end of a different, weakly constraining sentence. In Experiment 1, repeated words elicited a reduced N400 and an enhanced late positive complex (LPC) compared to words seen for the first time. Critically, there was no effect of initial sentence constraint on the size of the repetition effect in either time window. Thus, prediction violations did not accrue either costs or benefits for later processing. Experiment 2 used the same critical items and added strongly constraining filler sentences with expected endings to further promote prediction. Again, there was no effect of initial sentence constraint on either the N400 or the LPC to repeated critical words. When taken with prior findings, the results suggest that prediction is both powerful and flexible: It can facilitate processing of predictable information by reducing encoding effort without causing processing difficulties for unexpected inputs.

Keywords

Language comprehension; prediction; event-related potentials; N400; repetition

*Corresponding author (melinhl2@illinois.edu).

1. Introduction

Language comprehension is an inherently dynamic and fast-paced process that requires linkage of multiple levels of incoming information to both recent context and long-term knowledge. Despite the potential for variability at any level of a linguistic utterance (including phonology, morphology, syntax, and semantics), language also follows structured patterns, which comprehenders likely take advantage of to predict components of the upcoming message. An extensive body of literature attests that the processing of words that are predictable in their context is facilitated, whether measured through manual reaction times (Forster, 1981; Schwanenflugel & LaCount, 1988; Schwanenflugel & Shoben, 1985), eye movement behaviors (Altmann & Kamide, 1999; Ehrlich & Rayner, 1981), or measures of brain activity, such as event-related potentials (ERPs; e.g., Federmeier et al., 2002; Federmeier & Kutas, 1999b; Van Berkum et al., 2005). However, even with accumulating support for the view that being able to accurately anticipate upcoming input eases the burden of processing (e.g., Altmann & Mirković, 2009; Federmeier, 2007; Huettig & Mani, 2016), there remain questions about the extent to which incorrect predictions might incur processing costs (as suggested by, e.g., Jackendoff, 2002; see review by Van Petten & Luka, 2012). Thus, there has been increasing interest in uncovering what consequences prediction violations might have for processing at multiple levels and time points.

Across studies and methodologies, there are notable inconsistencies in the apparent consequences of encountering a word that is different from what might be expected from the context. For example, in a large scale natural reading study using eye-tracking, Luke and Christianson (2016) presented participants with passages from a variety of corpora and found that, replicating past work, early measures of gaze were slowed for words with low cloze probability (an operationalization of word predictability based on the proportion of participants from an independent norming group who completed the sentence with that word). However, when participants saw an unexpected but plausible word where a more predictable competitor was available – i.e., a “prediction violation” – reading times in late eye-tracking measures (regression path and total time) for the unexpected word actually appeared to be *facilitated*, rather than slowed. Corresponding findings were obtained in a more controlled experimental design in which both the sentence constraint of the experimental sentences as well as the cloze probability of the target words were manipulated (Frisson et al., 2017). The authors of both eye-tracking studies took their findings as evidence of there being no immediate costs associated with misprediction. In contrast, manual self-paced reading studies have found selective slowing to prediction violations, in the form of increases in the tail of the reaction time distribution (Ng et al., 2017; Payne & Federmeier, 2017). Moreover, similar violations in other studies are associated with event-related potential (ERP) effects that include a late, frontally-distributed positivity that is observed to unexpected words when these are encountered in strongly constraining sentence contexts wherein a different word was highly expected (DeLong et al., 2011; Federmeier et al., 2007; Payne & Federmeier, 2017; see also review by Van Petten & Luka, 2012). Thus, there are also indications that prediction violations alter, and potentially can disrupt, on-line processing.

Beyond the question of whether, in the short term, generating predictions and accommodating prediction violations may be taxing and/or incur processing costs, there are also uncertainties about the longer-term impact of prediction and prediction violations for learning and memory. One possibility is that encountering prediction violations boosts the resulting representation of the unexpected word, consistent with more general findings that memory is often enhanced by distinctiveness, surprise, or prediction error (e.g., Henson & Gagnepain, 2010; Hunt & Elliot, 1980; Konkle et al., 2010; McDaniel & Einstein, 1986) and in line with the role posited for prediction violations in models of implicit learning (e.g., Chang et al., 2006). Indeed, Hubbard et al. (2019) found that unexpected (compared to expected) endings elicited larger N1 and LPC amplitudes when they were later encountered on an explicit recognition test, suggesting enhanced attention (N1) and greater levels of explicit recollection (LPC). On the other hand, it is also possible that lingering representations of the originally predicted word (as found by Rommers & Federmeier, 2018a; see also Hubbard et al., 2019) could interfere with those of the unexpected words, creating downstream memory costs. Such interference might result if the predicted word acts as a competitor, creating demands on lexical selection processes. These results would be consistent with findings that increased lexical competition, such as between the potential meanings of ambiguous words, leads to greater difficulty in processing (Duffy et al., 1988; Rayner & Duffy, 1986) and poorer recall (Klein & Murphy, 2001).

To address the downstream consequences of encountering prediction violations for language processing and memory, the current study adapted a design introduced by Rommers and Federmeier (2018a). In two experiments, we used a repetition paradigm to probe the later representation of words originally encountered as prediction violations, compared to equally unexpected words that were simply weakly constrained. Participants read sentences that strongly constrained towards a specific word, thus inducing a strong prediction, but that ended with an unexpected (though still plausible) word, thus inducing a prediction violation. For example, given the sentence context *Be careful, the top of the stove is very…* 91% of participants in an offline task expected the ending to be the word *hot*. Here, instead, comprehenders were given the unexpected (albeit plausible) word *dirty* (cloze probability 0.03). The prediction-violating word (*dirty*) was then encountered again at the end of a weakly constraining sentence, several sentences after it had first been seen as a prediction violation. In a control condition, the critical word first appeared at the end of a weakly constraining sentence and was then likewise repeated at the end of another weakly constraining sentence. Participants read for comprehension as EEG was recorded.

As already discussed, a late, frontal positivity has been observed when comparing the immediate response to unexpected words that complete strongly constraining sentences versus equally unexpected words in sentence contexts that do not afford strong expectations (Federmeier et al., 2007). Although the exact cognitive and neural bases of this response remain unclear, its pattern of functional sensitivity, as a response to plausible words that violate strong expectations, has led to suggestions that it might index a processing “cost” associated with disconfirmed predictions, such as suppression of the previously predicted word or revision of expectations in relation to the established context (Brothers et al., 2015; DeLong et al., 2014).

What, then, happens when these two types of unexpected words are encountered again later? We expected to see repetition effects on the N400, a negative going wave form with central-posterior topography that peaks around 400 ms after presentation of a stimulus (for a review, see Kutas & Federmeier, 2011). The N400 has been linked to semantic access and is highly sensitive to repetition, such that repeated words elicited reduced N400s (Rugg, 1985). Observations of these patterns in both healthy controls and amnesic patients with compromised episodic memory strongly suggest that N400 repetition effects can be driven just by implicit memory processes (Olichney et al., 2000). If encountering prediction violations *enhances* word processing (by, e.g., capturing the reader's attention or promoting encoding of the prediction-violating word), we should see a larger influence of repetition (smaller N400) for the second presentation of the word that was initially processed as a prediction violation in a strongly constraining sentence. Additionally, we might observe an enhanced late positive complex (LPC) to those words' second presentation, reflecting enhanced explicit retrieval of the first appearance of the word. The LPC, which occurs in roughly the same time window as the frontal positivity but has a more posterior distribution, has been well-characterized in the memory literature and linked to retrieval from episodic memory. LPC amplitudes are enhanced for deeply encoded words compared to new words (Rugg et al., 1998), for repeated words that are retrieved during explicit memory tasks (Düzel et al., 1997; Rubin et al., 1999), and for recently encountered words that are spontaneously recognized (Kazmerski & Friedman, 1997; Paller et al., 1995; Van Petten & Senkfor, 1996). Alternatively, if lingering traces of the originally predicted word (Rommers & Federmeier, 2018b) cause interference, then first encountering a word as a prediction violation could subsequently lead to a *diminished* repetition effect on the N400 and/or the LPC.

In a second experiment, we set out to replicate the findings from Experiment 1 while also further incentivizing prediction. To that end, we increased the number of prediction confirming sentences by adding strongly constraining fillers ending with predictable words (the same ones from Rommers & Federmeier, 2018a). This ensured that participants encountered strong prediction confirmations as frequently as strong prediction violations, allowing us to test whether effect patterns from Experiment 1 would generalize across different distributions of critical word predictability.

2. Experiment 1

2.1. Methods

2.1.1. Participants—The final data set came from thirty volunteers (16 women and 14 men; mean age 20 years, range 18–25 years) from the University of Illinois community, who participated for course credit or payment. All were right-handed native monolingual English speakers with normal or corrected-to-normal vision and no prior history of neurological or psychiatric disorders. Data from 3 additional participants were recorded but later rejected for excessive artifacts during the critical word (>30% of trials).

2.1.2. Materials—Sentence stimuli consisted of 123 sentence triplets. Each triplet consisted of one strongly constraining sentence from Federmeier et al. (2007) and two weakly constraining sentence frames. All sentences in a triplet ended with the same word, which was an unexpected ending not only for the weakly constraining frames but also for the strongly constraining sentence (cloze value equal to or near 0). Ending type and position in the repetition sequence led to five sentence types, with 41 sentences for each type:

1. Prediction Violation: strongly constraining sentence frames, originally from Federmeier et al. (2007), which ended with an unexpected, but plausible, word
2. Previously Prediction Violation: weakly constraining sentence frames that appeared 3 sentences after a prediction violation sentence and ended with the same word
3. Unpredictable: weakly constraining sentence frames, adapted from Rommers and Federmeier (2018a, 2018b), which ended with the same unexpected words as in (1)
4. Previously Unpredictable: weakly constraining sentence frames that followed 3 sentences after an unpredictable sentence and ended with the same word
5. Not Previously Seen: weakly constraining sentences whose final critical word had not appeared previously in the block

The Previously Prediction Violation, Previously Unpredictable, and Not Previously Seen sentence types all featured the same critical sentence but differed in terms of the sentences preceding it. Table 1 shows examples, including two intervening filler sentences between the first and second presentation.

The sentences in the current study were modified from (Rommers & Federmeier, 2018a, 2018b) so that the final critical word of the weakly constraining sentence frames now matched with the endings of the Prediction Violation/Unpredictable sentences[1]. The degree of constraint of a sentence frame was operationalized as the cloze probability of its most frequently provided completion. As described in more detail in Rommers & Federmeier (2018a, 2018b), sentences were selected based on cloze probability norms collected from native English speakers on Amazon Mechanical Turk (www.mturk.com). In the norming task, participants were told to complete each sentence frame with “the word they would generally expect to find completing the sentence fragment”.

In the sentences used for the first presentation, the cloze probability of the critical word was nearly equal in the Prediction Violation sentences (0.002 ± 0.013, range 0.00–0.10) and the Unpredictable sentences (0.001 ± 0.007, range 0–0.05). However, the constraint of the two sentence types was different: Cloze probability of the most frequent completion in the strongly constraining Prediction Violation sentences was 0.86 ± 0.13, range 0.45–1.00, whereas in the weakly constraining Unexpected sentences it was 0.19 ± 0.08, range 0.05–0.35. Sentence length was matched (Prediction Violation: 10.02 ± 3.96 words, range 4–21; Unexpected: 10.02 ± 3.95 words, range 4–21). In the critical sentences used for the repetition conditions, the final word had a cloze probability of 0.0008 ± 0.006 (range 0–

[1]Several sentences from the Rommers & Federmeier studies could not be arranged such that they ended plausibly. Thus, nine sentences from Rommers & Federmeier’s full item list were included in the experiment to maintain the length of the blocks but were not included in analysis.

0.05) and the cloze probability of the most frequent completion was 0.18 ± 0.08 (range 0.05–0.35). The average length of the critical sentences was 8.08 ± 2.23 words (range 4–17 words). Critical words were rotated across repetition conditions, so visual input and all lexical variables were matched.

Three counterbalanced lists were created such that participants would see the critical word from each sentence triplet in only one condition. Each list included an additional 82 fillers, which ensured that over 70% of the sentence endings in a list did not constitute a repetition. The cloze probability of the sentence endings in fillers was 0.41 on average (range 0.24–0.68). The 282 sentences on each list were distributed across 13 blocks of 21 sentences and one block of 14 sentences.[2] Lists were pseudo-randomized individually for each participant. Specifically, following Rommers and Federmeier (2018a, 2018b), the trials within each block were ordered according to one of 29 (randomly selected, without replacement) pre-generated template trial sequences that satisfied our constraints, and then the order of the blocks was randomized. Critical word repetitions only occurred within a block. On repetitions, critical sentences were separated from the sentence containing the initial presentation by two unrelated sentences; these intervening sentences comprised fillers as well as first presentation sentences or critical sentences belonging to different triplets.

2.1.3. Procedure—Participants were seated in an electrically shielded recording booth approximately 100 cm in front of a 21-inch CRT computer monitor. Stimuli were presented in a white Arial font, size 20, on a black background. Each trial began with a centrally presented crosshair that stayed on the screen for 650 ms followed by a blank screen for 350 ms. Sentences were presented word by word, with each word appearing in the center of the screen for 200 ms with an interstimulus interval of 300 ms. After the final word of each sentence and an interstimulus interval of 1300 ms, three asterisks (* * *) appeared for 2 seconds, indicating that participants were free to blink. Participants took a short rest between blocks.

Participants were asked to minimize blinks, eye movements, and muscle movement while reading for comprehension with no additional task (i.e., participants did not see any comprehension questions during EEG recording). They were told that the EEG recording session would be followed by a paper-and-pencil memory test. The recording session began with three practice sentences to introduce participants to the task. Recording time was approximately one hour.

Following the recording session, participants completed a paper and pencil recognition test containing 246 words, half of which had been seen as sentence final words and the other half of which had not been seen during the recording session. Unseen words were matched in frequency and length with seen words. Participants were asked to circle all the words they recognized as a sentence-final word from the sentence-reading portion of the experiment.

[2]Dividing the total number of items across blocks resulted in a shortened final block in which participants saw two items in each experimental condition and four fillers.

2.1.4. EEG Recording & Processing—EEG was recorded from 26 evenly spaced silver-silver chloride electrodes mounted on a cap. Electrodes were referenced online to the left mastoid and re-referenced offline to the average of the left and right mastoids. Additional electrodes were placed on the outer canthus of each eye to monitor for horizontal eye movements and on the left infraorbital ridge to monitor for blinks. All electrode impedances were kept below 5 kΩ. Signals were amplified by a BrainVision BrainAmp DC, with a 16-bit A/D converter, an input impedance of 10 MΩ, a bandpass filter of 0.016–250 Hz, and a sampling rate of 1 kHz. The continuous EEG was high pass filtered offline through a 0.1 Hz filter (two-pass Butterworth with a 12 dB/oct roll-off). Raw waveforms were assessed trial-by-trial with artifact thresholds separately calibrated by visual inspection for each subject. Trials were excluded from averaging if they included blinks, large movement artifacts, signal drift, blocking, or a horizontal eye movement. On average, a total of 14% of trials (SD = 8%; range across conditions: 13.8%−15.6%; range across participants: 0%−29%) were marked as artifacts and not included in data analysis. This left an average of 32 trials (SD = 6, identical for all conditions) per condition for each participant in the final analysis.

2.1.5. Event-related potentials—ERPs were formed by averaging in the time domain for each condition and each participant, subtracting a 200 ms pre-stimulus baseline and applying a 20 Hz low-pass filter (two-pass Butterworth with a 24 dB/oct roll-off). At initial word presentation, we expected to observe an enhanced late frontal positivity to unexpected words encountered in strongly constraining sentence contexts, signaling that participants were predicting. Following previous work (Federmeier et al., 2007; Rommers & Federmeier, 2018b), we measured the frontal positivity as mean amplitude across 11 frontal channels (MiPf, LLPf, RLPf, LMPf, RMPf, LDFr, RDFr, LMFr, RMFr, LLFr, RLFr) in an a priori 500–800 ms window. Of primary interest were effects observed with repetition. To quantify the N400, mean amplitude measures were taken in an a priori 300–500 ms window, averaged across six centroparietal channels (LMCe, RMCe, MiCe, MiPa, LDPa, RDPa) where N400 amplitude is usually maximal (following Wlotko et al., 2012). The late positive complex (LPC) mean amplitude was measured in an a priori 500–800 ms window across the same six centroparietal channels, following Rommers & Federmeier (2018a, 2018b).

2.1.6. Data analysis—Trial-level responses (where 1 = judged “seen” and 0 = judged “not seen”) of the behavioral memory data were analyzed using a logistic mixed-effects regression model, which simultaneously accounts for participants and items as random effects (Baayen et al., 2008). Along with the fixed effect of Condition, by-item and by-participant random intercepts and by-item random slopes for Condition were entered as predictors (the model failed to converge when by-participant random slopes were included, which would have been the maximal random effect structure warranted by the design; Barr et al., 2013). The model was then compared to an identical model without the fixed effect of Condition using a likelihood ratio test.

ERPs at the first presentation of the critical words were analyzed using repeated measures analyses of variance (ANOVAs) with two levels of sentence constraint (critical word was initially a Prediction Violation in a strongly constraining sentence or was Unpredictable in a weakly constraining sentence). ERPs at the second presentation were similarly analyzed using repeated measures ANOVAs but with three levels of prior presentation (Previously Prediction Violation, Previously Unpredictable, and Not Previously Seen). Paired t-tests were used to conduct planned comparisons between the Previously Prediction Violation, Previously Unpredictable, and Not Previously Seen conditions.

2.2. Results

2.2.1. Memory performance—

Participants correctly recognized 37.75% of previously seen words, which was larger than the percentage of false alarms to unseen words (8.73%) by 29% (95% CI [25.5, 32.5]). This difference was found in all participants and led to a mean d' of 1.18 (95% CI [1.023, 1.338]). The larger hit rate to seen words than false alarm rate to unseen words across participants suggests that they were paying attention during the EEG session.

The repetition paradigm during sentence reading led to three sub-conditions in the recognition test: Seen Once, Seen First as Unpredictable, and Seen First as Prediction Violation. There was an effect of Condition, $\chi^2(2) = 54.549$, $p < 0.001$. Compared with the Seen Once words (28.7%), Seen First as Prediction Violation (42.7%) were recognized more often by 14.0% (95% CI [8.4, 19.6]), $\beta = 0.697$, $SE = 0.102$, $z = 6.856$, $p < 0.001$. Seen First as Unpredictable words (41.9%) were also recognized more often by 13.2% (95% CI [7.6, 18.8]), $\beta = 0.655$, $SE = 0.096$, $z = 6.862$, $p < 0.001$. There was no evidence for a difference between the Seen First as Prediction Violation and Seen First as Unpredictable conditions (0.8% difference, 95% CI [−3.4, 4.9]), $\beta = 0.041$, $SE = 0.094$, $z = 0.439$, $p = 0.660$. Thus, repetition enhanced performance, but differences in the predictability of the words during initial presentation did not measurably affect later recognition performance.

2.2.2. Event-related Potentials

Initial Word Presentation: Figures 1 and 2 shows the ERPs elicited by the first presentation of the critical words. Following sensory potentials expected for visual presentation (posterior P1, N1, P2; frontal N1, P2), a clear N400 was elicited in both conditions, followed by a late positive-going wave. As expected, in the time window of the frontal positivity, responses to Prediction Violations were more positive than to Unexpected words over anterior electrode sites by 0.88 μV (95% CI [0.13, 1.62]), $F(1,29) = 5.837$, $p = 0.022$, see Figure 2). However, a similar difference could also be observed over the six centroparietal electrode sites in the same 500–800 ms time window (1.57 μV difference, (95% CI [0.73, 2.41]). Differences between the conditions over those sites seemed to begin in the P2 window, with larger P2 responses to unexpected words that appeared in strongly versus weakly constraining sentences, and then continued into the N400 window.[3] Similar P2 effects of sentential constraint have been seen in some (Wlotko & Federmeier, 2007) but not other (Rommers & Federmeier, 2018a, 2018b) studies using these same stimuli. Thus, although we observed the expected frontal effect at initial presentation, the presence of an earlier difference and a posterior effect complicates interpretation.

[3]Exploratory analyses over combined frontal and centroparietal sites in a 190–240 ms window showed a difference of 0.86 μV (95% CI [0.28, 1.44]) and a 1.48 μV difference, (95% CI [0.75, 2.22]) over centroparietal sites in the N400 window.

Critical, Repeated Words: Figure 3 shows the ERPs elicited by the critical words in the repetition sentences. Condition-related differences were apparent in the N400 time window and continued into the LPC. N400 amplitude differed between conditions, $F(2,58) = 17.191$, $p < 0.001$ (Greenhouse-Geisser corrected; $\varepsilon = 0.972$). Relative to the Not Previously Seen words, which elicited the largest N400, the N400 in response to Previously Unpredictable words was attenuated by 1.46 μV (95% CI [0.92, 2.00]), $F(1,29) = 30.829$, $p < 0.001$. The N400 in response to Previously Prediction Violation words was attenuated by 1.21 μV (95% CI [0.70, 1.72]), $F(1,29) = 23.715$, $p < 0.001$. Thus, both predictable and unpredictable words elicited repetition effects on the N400 when presented again. Although the repetition effect for Previously Prediction Violation words was numerically smaller than that for Previously Unpredictable words by 0.25 μV, this difference was statistically nonsignificant (95% CI [−0.33, 0.84]), $F(1,29) = 0.779$, $p = 0.385$.

The amplitude of the late positive complex (LPC) also differed between conditions, $F(2,58) = 10.216$, $p < 0.001$ (Greenhouse-Geisser corrected, $\varepsilon = 0.950$). Relative to the Not Previously Seen words, LPC amplitude in response to Previously Unpredictable words was more positive by 1.39 μV (95% CI [0.76, 2.02]), $F(1,29) = 20.069$, $p = 0.0001$. The LPC in response to Previously Prediction Violation words was more positive by 1.05 μV (95% CI [0.45, 1.67]), $F(1,29) = 12.806$, $p = 0.001$. The LPC to Previously Unpredictable words did not significantly differ from the Previously Prediction Violation words (0.34 μV difference, 95% CI [−0.40, 1.06]), $F(1,29) = 0.900$, $p = 0.351$).

Overall, then, repetition effects were obtained on N400 and LPC, replicating past findings with this paradigm. Critically, however, these effects did not significantly differ between Previously Unpredictable words and Previously Prediction Violations.

2.3. Experiment 1 Discussion

Participants in Experiment 1 read strongly or weakly constraining sentences with unexpected, but plausible, endings. Three sentences later, the critical sentence-final word appeared again at the end of a weakly constraining sentence. In a comparison condition, the critical word was seen only once at the end of a weakly constraining sentence. Sentences in both second presentation conditions showed the well-established facilitative effects of repetition, with repeated words eliciting a reduced N400 as well as an enhanced LPC. However, there were no differences observed on either the N400 or the LPC for words that had previously appeared as prediction violations (Previously Prediction Violation) versus as unexpected completions of weakly constraining contexts (Previously Unpredictable), which did not afford a clear prediction. A similar pattern was seen in results from a paper-and-pencil recognition test of the critical words, wherein there was a clear benefit of repetition but no effect of prior predictability. Taken together, the results of Experiment 1 suggest that processing prediction-violating words ultimately affords neither cost nor benefit to reprocessing of the word when it is seen again downstream.

To ascertain that participants were, in fact, predicting, we examined the frontal positivity at the time the two types of unexpected words were encountered. As expected, we observed a larger positivity to the prediction violations than to the weakly constrained unexpected words. However, the conditions also manifested earlier differences, likely due to the differing constraint of the sentence contexts, which have also led to early effects in some other studies (e.g., Federmeier et al., 2005; Wlotko & Federmeier, 2007). Such effects have often been attributed to the differential deployment of attentional resources in strongly versus weakly constraining sentences (see also Rommers et al., 2017). We additionally observed a posterior effect in the late time window, which was also divergent from the prior findings from Rommers and Federmeier. Therefore, we decided to run a second experiment using the same critical conditions to both try to replicate the critical repetition findings and to further examine the consistency of the first presentation effect(s).

Moreover, a second experiment offers the opportunity to try to strengthen the prediction violation manipulation. In Experiment 1 all of the strongly constraining sentences ended with unexpected words. Although there were medium constraint fillers that ended predictably, the fact that predictions were so often violated could have tended to disincentivize participants from engaging in prediction. Thus, we adapted the follow-up experiment to further encourage the use of prediction. In Experiment 2, participants read the same critical stimuli from the Previously Prediction Violation and Previously Unpredictable conditions of Experiment 1. However, to ensure that participants saw as many expected as unexpected words in strongly constraining contexts, we replaced the Not Previously Seen condition[4] with the strongly constraining sentences from Rommers & Federmeier (2018a), all of which ended with the most predicted word. In this follow-up experiment, we expected, at initial presentation, to see N400 responses graded by cloze probability (e.g., Kutas & Hillyard, 1984), with reduced amplitudes to high cloze probability completions compared to both types of unexpected words. We also expect to see a post-N400 anterior positivity selective to the unexpected words in the strongly constraining sentences. Downstream, if we replicate the findings from Experiment 1, we expect to find no differences in N400 or LPC responses to repetitions of the two types of unexpected words.

3. Experiment 2

3.1. Methods

3.1.1. Participants—The final data set again came from 30 participants (14 women and 16 men; average age 19.4 years, range 18–22 years) recruited from the University of Illinois community, who participated for course credit. All were right-handed native monolingual English speakers with normal or corrected-to-normal vision and no prior history of neurological or psychiatric disorders. Data from 8 additional participants were recorded but later rejected for excessive artifacts during the critical word (>30% of trials). The larger number of rejected participants in Experiment 2 is likely due to the greater number of sentences, which made the experiment longer and more tiring. None of the participants had previously participated in Experiment 1.

[4]Note that replacing this condition means we will not have the comparison for assessing the overall size of the repetition effect compared to items seen only once. However, basic N400 repetition effects are well-established, not only in Experiment 1 but also in the prior studies (Rommers & Federmeier, 2018a, 2018b) and in the wider literature. In Experiment 2, the critical comparison continues to be between the Previously Unpredictable and Previously Prediction Violation conditions, both of which are repeated in the same sentence frame.

3.1.2. Materials—Critical sentence stimuli from Experiment 1 (except for the Not Previously Seen condition) were combined with the Predictable and Unpredictable items from Rommers & Federmeier (2018a). Ending type and position in the repetition sequence led to six sentence types:

1. Prediction Confirmation: strongly constraining sentence frames, originally from Federmeier et al. (2007), which ended with an expected word
2. Unpredictable with matched Prediction Confirmation ending: weakly constraining sentence frames from Federmeier et al. (2007), which ended with the same expected word as in (1)
3. Prediction Violation: unchanged from Experiment 1
4. Previously Prediction Violation: unchanged from Experiment 1
5. Unpredictable with matched Prediction Violation ending: sentences from the Unpredictable condition from Experiment 1, unchanged
6. Previously Unpredictable: unchanged from Experiment 1

The Previously Prediction Violation and Previously Unpredictable sentence types once again featured the same critical sentence but differed in the sentences preceding it. To simplify ERP analyses, the two weakly constraining initial sentences – Unpredictable with matched Prediction Confirmation ending and Unpredictable with matched Prediction Violation ending – were combined into a single Unpredictable condition to be used as a comparison with both Prediction Confirmation and Prediction Violation sentences. Table 2 shows examples, including two intervening filler sentences between the first and second presentation.

Three counterbalanced lists were created such that participants would see the critical word in only one condition. As in Experiment 1, the lists included an additional 82 fillers, which ensured that 75% of the sentence endings in a list did not constitute a repetition. The 328 sentences on each list were distributed across 13 blocks of 24 sentences and one block of 16 sentences. Lists were pseudo-randomized individually as in Experiment 1. On repetitions, critical sentences were separated from the sentence containing the initial presentation by two unrelated sentences; these intervening sentences comprised fillers as well as first presentation sentences or critical sentences belonging to different triplets.

3.1.2.1. Recognition test: The 123 predictable endings (which were only seen once) from Rommers & Federmeier (2018a) were added to the recognition test from Experiment 1, along with an additional 52 matched words that had not appeared in any of the stimuli. The final test consisted of 267 words, 144 of which had been seen as sentence final words for any given participant and the remaining 123 of which had not been seen during the recording session.

3.1.3. Procedure—The experimental procedure was the same as Experiment 1. Participants again took a paper and pencil recognition test following the EEG recording session.

3.1.4. EEG Recording & Processing—EEG recording, baselining, and trial exclusion procedures were the same as Experiment 1. On average, a total of 20% of trials (SD = 8%; range across participants: 5%−30%; range across conditions 19.1%−23.0%) were marked as artifacts and not included in data analysis. This left an average of 30 trials (SD = 7, identical across conditions) per condition for each participant in the final analysis.

3.1.5. Event-related potentials—As in Experiment 1, ERPs were formed by averaging in the time domain for each condition and each participant, subtracting a 200 ms pre-stimulus baseline and applying a 20 Hz low-pass filter. At initial word presentation, we measured N400 amplitudes in an a priori 300–500 ms window, averaged across the LMCe, RMCe, MiCe, MiPa, LDPa, and RDPa channels (as in Rommers and Federmeier 2018a; 2018b), and frontal positivity amplitude, as in Experiment 1, in an a priori 500–800 ms window across the 11 frontal channels (MiPf, LLPf, RLPf, LMPf, RMPf, LDFr, RDFr, LMFr, RMFr, LLFr, RLFr). At repetition, N400 and LPC effects were measured as in Experiment 1 (300–500 ms and 500–800 ms at the same 6 central-posterior electrodes).

3.1.6. Data analysis—The logistic regression model analyzing trial-level responses for the behavioral memory test was nearly the same as in Experiment 1, with the addition of one new condition and renaming of another (see Experiment 2 results section). The model was again compared to an identical model without the fixed effect of Condition using a likelihood ratio test.

ERPs at the first presentation of the critical words were analyzed using repeated measures ANOVAs with three levels of sentence constraint (critical word was initially a Prediction Violation, was Unpredictable, or was a Prediction Confirmation). Paired t-tests were used to conduct planned follow-up comparisons between the Prediction Violation, Unpredictable, and Prediction Confirmation conditions. ERPs at the second presentation were analyzed using repeated measures ANOVAs with two levels of prior presentation (Previously Prediction Violation and Previously Unpredictable).

3.2. Results

3.2.1. Memory performance—Participants correctly recognized 32.93% of previously seen words, which was larger than the percentage of false alarms to unseen words (13.43%) by 19.5% (95% CI [15.7, 23.2]). This difference was found in all participants and led to a mean *d'* of 0.749 (95% CI [0.615, 0.882]), suggesting participants were paying attention during the EEG session.

The inclusion of items from Rommers & Federmeier (2018a) with the items in the repetition paradigm during sentence reading led to four sub-conditions in the recognition test: Seen Once as Prediction Confirmation, Seen Once as Unpredictable, Seen First as Unpredictable, and Seen First as Prediction Violation. There was an effect of Condition, $\chi^2(3) = 31.586$, $p < 0.001$. Both of the conditions wherein words were seen twice showed better memory than conditions in which words were seen only once. Compared with the Seen Once as Prediction Confirmation (24.1%) and Seen Once as Unpredictable words (28.3%), Seen First as Prediction Violation (39.9%) were recognized more often by 15.8% (95% CI [11.1, 20.4]), $\beta = 0.780$, $SE = 0.144$, $z = 5.421$, $p < 0.001$, and 11.6% (95% CI [6.9, 16.3]), $\beta = 0.529$, $SE =$

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0.139, $z = 3.808$, $p = .0001$, respectively. Seen First as Unpredictable words (39.2%) were recognized more often by 15.1% (95% CI [10.4, 20.0]), $\beta = 0.755$, $SE = 0.145$, $z = 5.218$, $p < 0.001$ and 10.9% (95% CI [7.2, 14.8]), $\beta = 0.504$, $SE = 0.140$, $z = 6.862$, $p = .0003$, respectively. There was no evidence for a difference between the Seen First as Prediction Violation and Seen First as Unpredictable conditions (0.7% difference, 95% CI [−4.3, 5.5]), $\beta = 0.024$, $SE = 0.105$, $z = 0.231$, $p = 0.817$. Thus, results from Experiment 1 replicated, with repetition enhancing performance but differences in the predictability of the words during initial presentation failing to measurably affect later recognition performance.

3.2.2. Event-related Potentials

Initial Word Presentation: Figures 4 and 5 show the ERPs elicited by the words at the end of Prediction Confirmation sentences and the first presentation of the critical words in Prediction Violation sentences and Unpredictable sentences. Following sensory potentials expected for visual presentation (posterior P1, N1, P2; frontal N1, P2), there was, as expected, an effect of condition on the N400, $F(2, 58) = 41.185$, $p < 0.001$ (Greenhouse-Geisser corrected, $\varepsilon = 0.822$). Consistent with canonical findings, Prediction Confirmation words elicited a reduced N400 amplitude in comparison to Unpredictable words (2.97 μV difference, (95% CI [2.309, 3.632]), $F(1,29) = 84.4$, $p < 0.001$) and to Prediction Violation words (3.02 μV difference, (95% CI [2.075, 3.958]), $F(1,29) = 42.9$, $p < 0.001$). The earlier difference observed in Experiment 1 between Unpredictable and Prediction Violation words did not appear in Experiment 2 (0 .04 μV difference, (95% CI [−0.659, 0.751]), $F(1, 29) = 0.0178$, $p = 0.895$).

As in Experiment 1, pairwise comparisons showed that Prediction Violations were more positive compared to Unpredictable words over anterior electrode sites by 0.756 μV (95% CI [0.17, 1.34]), $F(1,29) = 7.023$, $p = 0.013$). The anterior response to Prediction Confirmation words did not differ from that to Unpredictable words (0.23 μV difference, (95% CI [−0.945, 0.488]), $F(1,29) = 0.425$, $p = 0.520$).

Critical, repeated words: Figure 6 shows the ERPs elicited by the repeated critical words. There were no differences between the critical repeated conditions in any time window. As in Experiment 1, the N400 to Previously Unpredictable words did not significantly differ from the Previously Prediction Violation words (0.47 μV difference, (95% CI [−0.304, 1.238]), $F(1,29) = 1.532$, $p = 0.226$). The LPC to Previously Unpredictable words also did not significantly differ from the Previously Prediction Violation words (0.08 μV difference, (95% CI [−0.84, 0.64]), $F(1,29) = 0.047$, $p = 0.830$). Overall, then, replicating Experiment 1, there was no evidence for downstream effects of encountering a prediction violation compared to the effect of processing a matched, unpredictable word that completed a weakly constraining sentence frame.

3.3. Experiment 2 Discussion and Comparison Between Experiments

In Experiment 2, participants once again read strongly or weakly constraining sentences ending with an unexpected, but plausible word. The final word would then be seen again three sentences later at the end of a weakly constraining sentence. To encourage the use of prediction during reading, strongly and weakly constraining sentences ending with predictable words were used as additional fillers. Due to constraints in counterbalancing items across the two stimulus sets (both of which used overlapping materials from Federmeier et al. (2007), the control condition from Experiment 1 was removed, so that the absolute size of the repetition effect could not be ascertained. However, the critical comparison continued to be between the Previously Unpredictable and Previously Prediction Violation words, which were the same lexical items repeated in the same weakly constraining contexts.

Indeed, the critical findings replicated in the second experiment. ERPs to Previously Prediction Violation and Previously Unpredictable items were not detectably different in either the N400 or the LPC time windows. Moreover, results from the explicit recognition test once again only showed benefits of repetition and no effect of the context in which the critical word initially appeared. Figure 7 graphs the mean amplitudes from the two experiments in the N400 and LPC time windows side by side. Overall mean amplitudes from the repetition conditions were essentially equivalent across the two experiments in the N400 time window. In the LPC time window, mean amplitudes from the repetition condition in Experiment 2 were overall a bit smaller than in Experiment 1[5]. Critically, what is apparent is the null effect of prior predictability in both the N400 and the LPC time windows for both experiments. To test for the degree of support for the null effect of prior predictability, Bayes factor (BF) analyses were conducted on the pooled data from both experiments over the six central-posterior channels for the N400 and LPC time windows using the anovaBF function of the BayesFactor package in R with default parameters. These analyses returned moderate support for the null hypothesis that prior predictability had no effect on N400 or LPC amplitudes of repeated words (between 300–500 ms, $BF_{01} = 5.00$; between 500–800 ms, $BF_{01} = 4.56$). Thus, the combined results support the interpretation that a previous prediction violation has neither a beneficial nor a costly effect on downstream processing.

Moreover, the similarity in the repetition findings was obtained across different stimulus environments and somewhat different patterns of ERP results for initial presentations. In both experiments, Prediction Violations elicited a post-N400 frontal positivity compared to weakly constraint Unexpected Words. This frontal positivity has been linked to the processing of information that violates a strong prediction (e.g., Federmeier et al., 2007; Thornhill & Van Petten, 2012), and thus can serve as evidence that participants were processing predictively. In Experiment 1, however, there were also earlier constraint-based differences, beginning as early as the P2, and a broader post-N400 effect topography that complicated interpretation of the effect pattern in the post-N400 time window. In Experiment 2, however, those earlier effects did not obtain. ERP patterns in the N400 time window were aligned with previous literature, such that expected words in strongly constraining sentences showed reduced N400 amplitudes compared to unexpected words, which, in turn, did not show differential N400 effects as a function of constraint (Federmeier et al., 2007; Kutas & Hillyard, 1984; Rommers & Federmeier, 2018b). Moreover, again replicating past work, the frontal positivity was selectively enhanced to prediction violations,

[5]It is possible that explicit recognition of the repetitions was reduced in Experiment 2 compared to Experiment 1, although absolute amplitude measurements between subject populations do not afford strong conclusions. Comparisons of the behavioral recognition data show a higher *d'* from Experiment 1 than Experiment 2 (1.18 vs. 0.749), consistent with reduced explicit recognition.

compared to both weakly constrained unexpected words and prediction confirmations (e.g., Brothers et al., 2015; Federmeier et al., 2007; see also Van Petten & Luka, 2012). Importantly, then, we find the same pattern of response on the critical repetition items irrespective of whether early constraint effects are or are not observed at first presentation and across stimulus environments with different proportions of strong constraint sentences and of prediction confirmations, suggesting that these findings can be generalized.

4. General Discussion

The goal of this study was to examine the downstream impact of processing a prediction violation, and, more specifically, to determine whether making a prediction and having it violated would increase or decrease subsequent memory signals for that violating word. Although historical arguments against prediction have largely been abandoned in the face of both behavioral and electrophysiological evidence demonstrating the facilitative influence of prediction-based expectancy on comprehension, important questions remain about how comprehenders cope with the consequences of invalid predictions.

Understanding the nature of predictions and their consequences is complicated by emerging evidence suggesting that although prediction can serve to facilitate language processing, it is not ubiquitous. For example, ERP data from older adults do not mimic patterns suggestive of prediction: Older adults as a group do not show facilitation for anomalous words related to a predicted completion and do not exhibit the frontal positivity in response to prediction violations (Federmeier et al., 2010; Wlotko et al., 2012), nor do they show an N400 effect for articles preceding unexpected nouns (DeLong et al., 2012). Second language (L2) speakers have similarly demonstrated a lack of a frontal positivity when comprehending in their L2 (Moreno & Kutas, 2005) as well as a lack of an N400 effect at articles preceding unexpected words (Martin et al., 2013). Reduced patterns of predictions have likewise been observed in low-literate adults' ERPs and self-paced reading times (Ng et al., 2017) as well as in their anticipatory fixations to visual objects (Mishra et al., 2012). Finally, even among the native-speaking college-aged population, use of prediction does not seem to be ubiquitous but, instead, reflects mechanisms that are characteristic of how the left cerebral hemisphere – but not the right hemisphere – processes language (Federmeier & Kutas, 1999a). The results from these studies thus indicate that the impacts of prediction unfold in multifaceted ways over time, which could make understanding how prediction affects behavior much less straightforward than originally believed. Namely, for all the benefits of facilitated processing that prediction can afford, it is also unlikely to be prevalent, useful, or necessary during all instances of language processing over the course of the lifespan (see Huettig & Mani, 2016 for further discussion). Thus, it becomes important to understand the conditions under which prediction may *not* be beneficial – such as when it might be associated with processing costs.

One possible condition under which prediction could entail costs is when strong predictions are violated, which could be disruptive to comprehension, especially since there is evidence that incorrect predictions can linger for some time after being disconfirmed (Hubbard et al., 2019; Rommers & Federmeier, 2018b). On the other hand, some have suggested that incorrect predictions are in fact useful for language learning and adaptation (e.g., Chang et al., 2006) or for memory encoding (Henson & Gagnepain, 2010). With the emerging evidence that prediction is a multifaceted, non-ubiquitous process with otherwise unclear consequences on later processing, it becomes apparent that an investigation into the downstream effects of both valid and invalid predictions is required to understand the mechanism underlying prediction, as well as its role in language comprehension, as a whole.

Across different measures, the present study showed no reliable downstream consequences of prediction violations. First, N400 amplitude was reduced for repeated words, with no significant difference between words that first appeared as prediction violations or as unpredictable words in a non-predictive context. Because the N400 has been closely linked to relatively automatic processes of semantic access (see Kutas & Federmeier, 2011 for further discussion), attenuated N400 amplitudes to repeated stimuli can be thought of as reliable indicators of implicit recognition. Second, no downstream effect of prediction violation was observed on the LPC, which can be thought of as an indicator for *explicit* recognition, since LPC repetition effects are linked to retrieval from episodic memory (e.g., Düzel et al., 1997; Rubin et al., 1999; see Olichney et al., 2000 for a direct comparison of N400 and LPC in amnesic patients). Third, results from a paper-and-pencil recognition test conducted after EEG recording followed a similar pattern, with clear benefits of repetition, but no measurable differences between first presentation type. All of these findings were replicated in a second experiment that included additional prediction-confirmation filler sentences to further encourage participants' use of prediction while reading. Thus, across three measures of downstream memory (implicit at the N400, explicit at the LPC, and behavioral recognition), the consistent lack of an effect of prediction violations builds towards the same conclusion: that prior predictability has no effect on downstream memory for the prediction-violating word.

These results therefore support the view that encountering a word that violates a prediction built from sentential context ultimately incurs neither cost nor benefit to downstream processing of the unexpected word. Such a finding appears to be in line with the results of Luke & Christianson (2016) and Frisson et al. (2017), who also found no costs of misprediction in late reading measures. Thus, while early skeptics of prediction once argued that language was inherently unpredictable, and that the risk of misprediction could lead to processing costs (e.g., Forster, 1981; Jackendoff, 2002), this type of experimental evidence suggests that the language processor is able to effectively process unexpected words, even when these constitute prediction violations. Although information about incorrect predictions lingers (as shown by Rommers & Federmeier, 2018b), it does not seem to notably interfere with encoding of the words that replaced those predictions. On the other hand, misprediction does not appear to hold any downstream benefit to memory either, at least as indexed by responses to incidental word repetitions.

These experiments were designed as follow-up studies to the repetition experiments of Rommers & Federmeier (2018a, 2018b) and, together with that data, present a picture of what the downstream consequences of predicting are like. In Rommers & Federmeier (2018a), sentences ended with a predictable or unpredictable word, which then appeared again three sentences later. Results showed a less robust repetition effect at the N400 for repeated words that had initially appeared as predictable endings than for those that had appeared in weakly constraining sentences. Moreover, whereas repetitions of previously unpredictable words showed an LPC repetition effect, repetitions of prediction confirmations did not. Both results suggest that correctly predicting a word led to a more impoverished representation downstream. In another study, Rommers & Federmeier (2018b) changed the endings of their strongly constraining sentences to unexpected but plausible words and left all of their weakly constraining sentences from first and second presentations unchanged. Thus, participants mispredicted words in strongly constraining sentences but then saw their original prediction three sentences later. The results showed what the authors dubbed a "pseudo-repetition" effect: compared to words seen for the first time (and never predicted), N400 amplitude was reduced for words that had previously been predicted (but were never presented), although this effect was smaller than that for overt repetition. On the LPC, however, repetition effects only obtained for words that were actually repeated. These findings suggest that violating a prediction was not enough to fully revise expectations and that a representation of the originally predicted word lingered in memory long enough to have an impact three sentences later, on measures linked to implicit – though not explicit – memory. Hubbard et al. (2019) came to a similar conclusion after observing that participants false alarmed to predicted "lures" (words that were predicted but not seen) more often than to new items in a behavioral recognition test. They also observed that false alarms to strongly predicted items correlated with an N400-like pattern, suggesting that false recognition of strongly predicted, but not seen, items was driven by an increased sense of conceptual fluency. Together the results of these studies, in conjunction with the current findings, suggest that prediction may work to facilitate processing by instantiating upcoming words in ways that have lasting consequences. In the process of such instantiation, the system seems to engage in less thorough processing of an incoming item that matches the prediction. Put another way, while prediction does allow for easier processing, it does so at the expense of the strength of encoding of the incoming word.

Interestingly, whereas effects of the original prediction can be seen clearly, both on the processing of that word when obtained as well as downstream, the current findings suggest that the effects of misprediction on unexpected words may be more short-lived. Although such prediction violations are associated with changes in brain activity when they are encountered, we did not see downstream differences in memory for prediction-disconfirming words compared to words that were simply unexpected. Thus, on the one hand, the lingering activation of the predicted word does not seem to interfere with the representation of the prediction violation that replaced it. On the other hand, the processing reflected in the post-N400-positivities that are elicited by prediction violations – which some have suggested may reflect a conflict detection process and/or a process of revising one's interpretation of the unfolding sentence (Federmeier et al., 2007; Rommers & Federmeier, 2018a, 2018b) – does not seem to augment the encoding of the prediction violation or make it somehow more memorable, at least in the context of ongoing sentence comprehension tasks. This pattern is informative for models of error-driven memory or implicit learning, which assume that incorrect predictions elicit error signals with important consequences for, e.g., subsequent predictions (e.g., Dell & Chang, 2014; Henson & Gagnepain, 2010). In the error-driven learning literature, ERPs have been posited as neural byproducts of prediction errors as they are processed through a learning algorithm that then informs the generation of new predictions (Fitz & Chang, 2019). Within this framework, ERPs downstream of prediction errors might reflect some degree of learning as the system incorporates the previous error signal to make more informed predictions. Here, we did not see clear downstream consequences of prediction error. However, it should be noted that the current experiments, as well as the study by Hubbard et al. (2019), focused specifically on the processing of and memory for the sentence-final word. Memory benefits following prediction violations might still accrue for other information, including the content of the sentence itself, and the locus of error-driven memory benefits may not be on the prediction-violating word as such.

When taken in conjunction with studies by Rommers and Federmeier (2018a, 2018b), the current findings paint a portrait of the prediction mechanism as a language processing tool that is both powerful and flexible. Prediction allows the comprehender to anticipate the arrival of incoming words in the hopes of facilitating processing, in part by virtue of reducing the demands of stimulus encoding for the predictable item. However, at times when the prediction is violated, the system is still able to efficiently process the unexpected word, without notable interference from the lingering representation of the original prediction.

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- Encountering prediction violations in sentences does not enhance word memory
- Implicit & explicit memory signals do not vary for words that violated predictions
- Violating predictions during reading neither benefits nor harms comprehension
- Prediction benefits in-the-moment processing with little risk of downstream impact

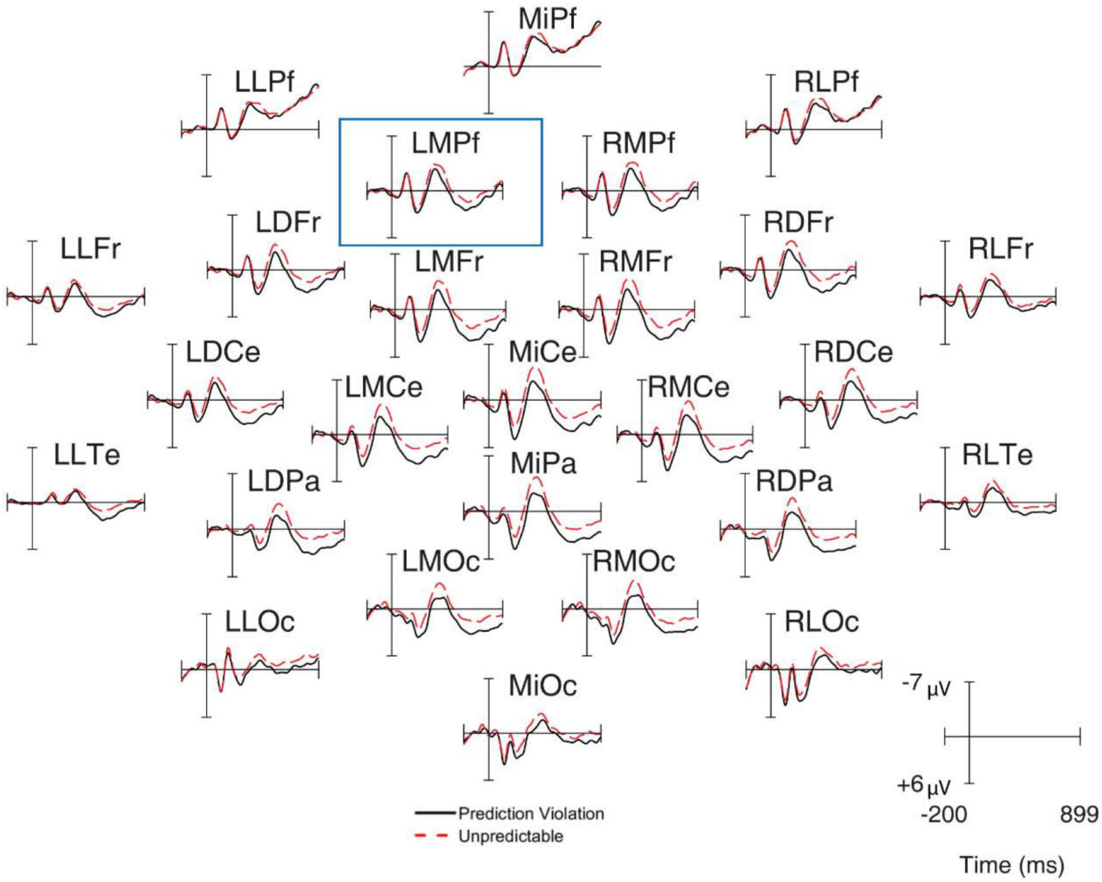

Figure 1.

Grand-average ERPs at all scalp electrode sites time-locked to words upon initial presentation. Words were prediction violations (seen in strongly constraining contexts) or unpredictable (seen in weakly constraining sentence) Negative is plotted up. A frontal channel (LMPf, boxed) is shown close up in Fig. 2.

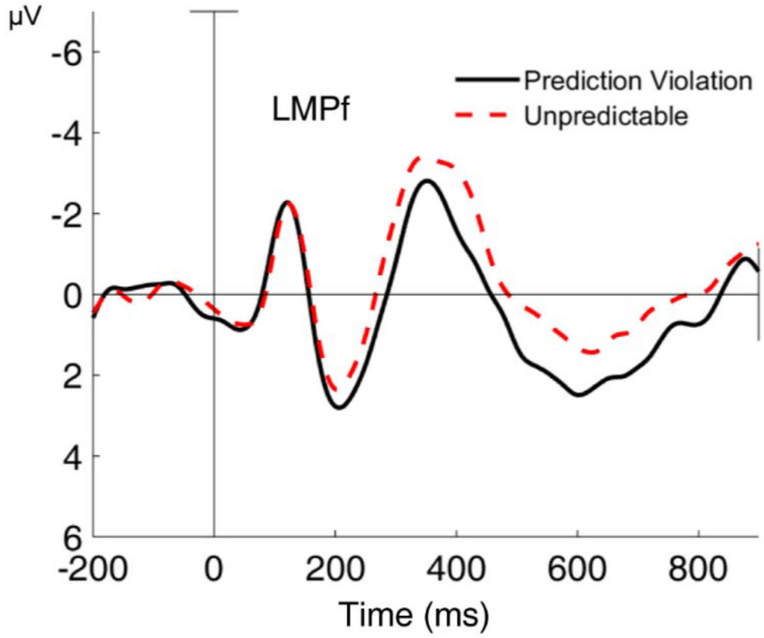

Figure 2.

Close-up of a frontal channel (LMPf) from Fig. 1 depicting a post-N400 positivity to the Prediction Violation.

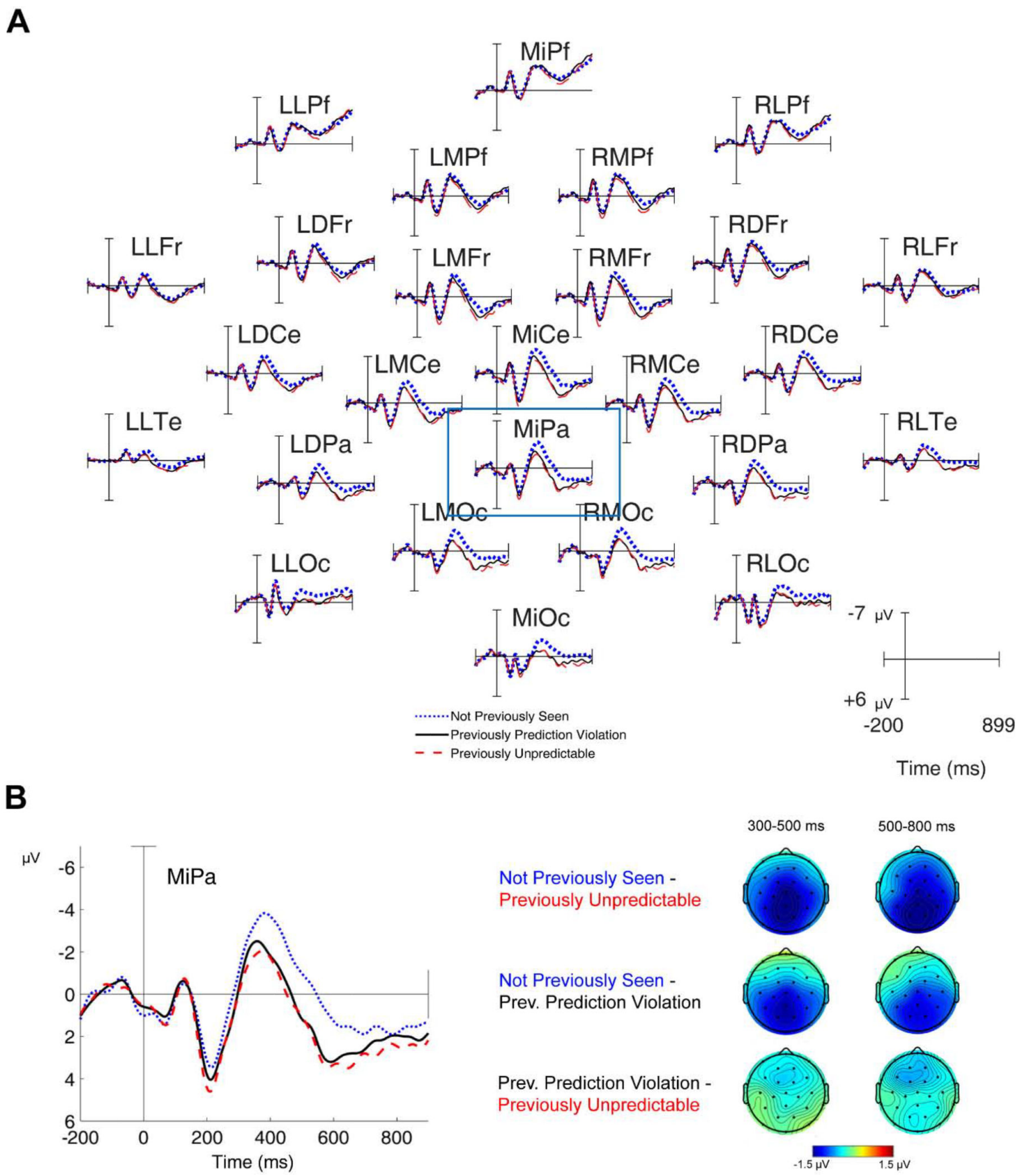

Figure 3.

Grand-average ERPs time-locked to critical words in the critical weakly constraining sentences. The words were either repetitions (Previously Prediction Violation, Previously Unpredictable) or unseen words presented in the same sentence contexts (Not Previously Seen). A) All scalp electrode sites. B) Close-up of a central channel (MiPa) showing the N400 and LPC, along with scalp topographies of the repetition effect for Previously Unpredictable words, the repetition effect for Previously Prediction Violation words, and the effect of prior prediction violation.

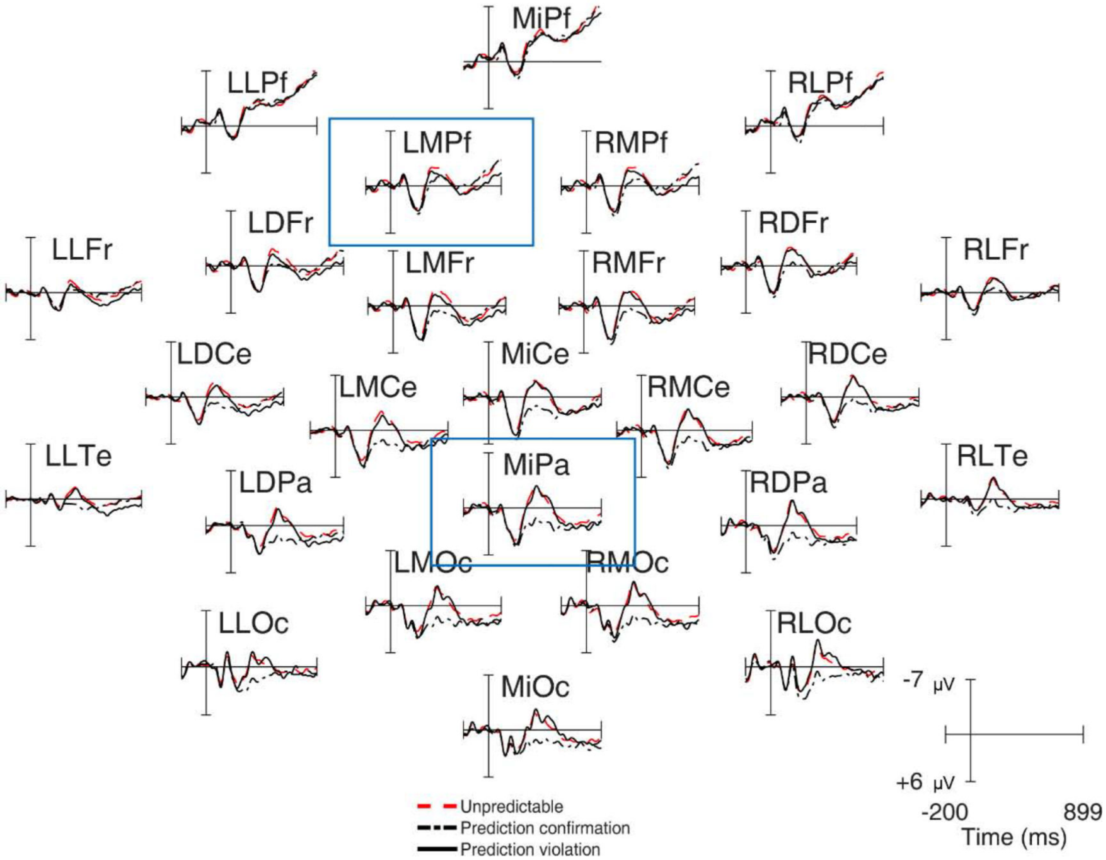

Figure 4.
Grand-average ERPs time-locked to words upon initial presentation at all scalp electrode sites. Words were prediction violations or prediction confirmations (presented in strongly constraining contexts) or unpredictable (presented in weakly constraining sentence). Negative is plotted up. Close-ups of a central channel (MiPa) and of a frontal channel (LMPf), both boxed, are shown in Fig. 5.

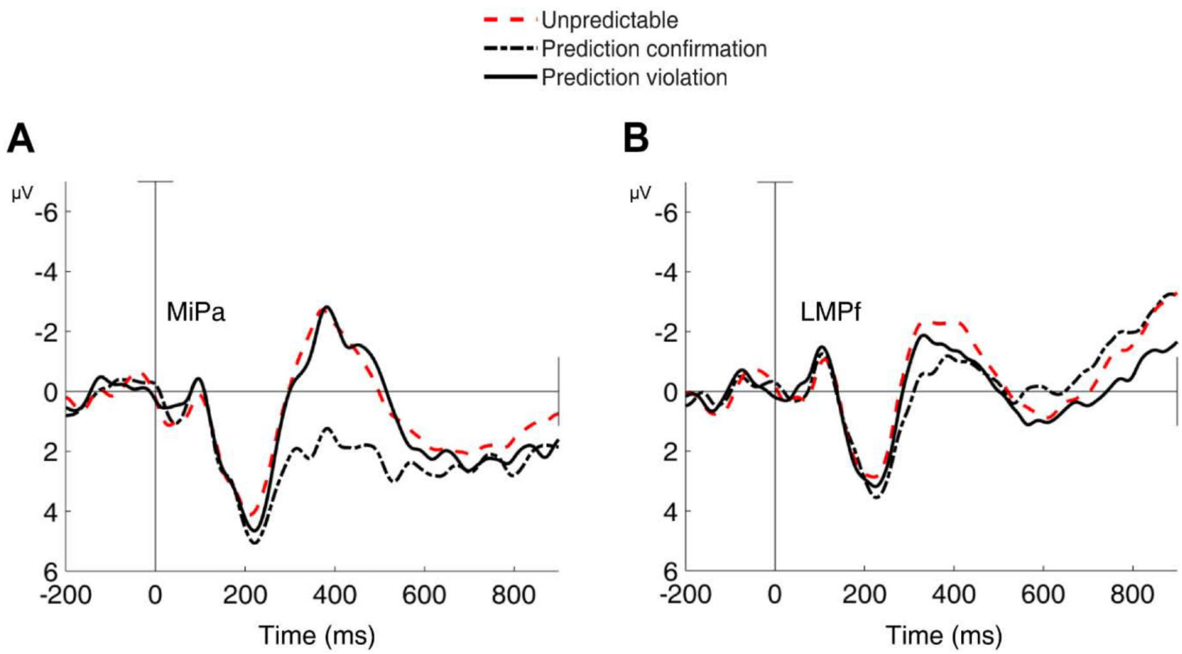

Figure 5.

Close-ups of two channels from Fig. 5 A) A central channel (MiPa) showing an attenuated N400 for Prediction Confirmations. B) A frontal channel (LMPf) depicting a post-N400 positivity to Prediction Violations.

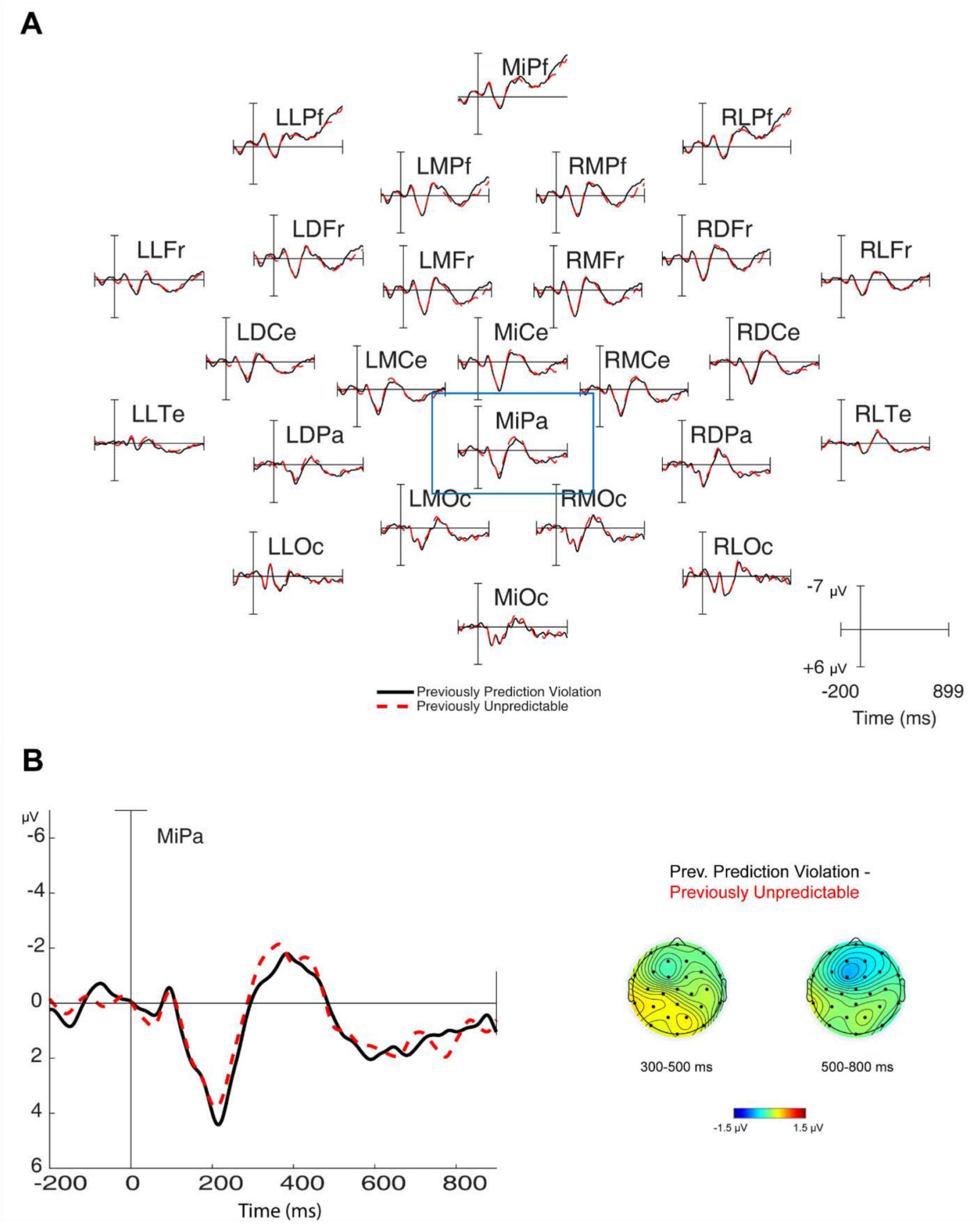

Figure 6.

Grand-average ERPs time-locked to critical words in the weakly constraining Previously Prediction Violation and Previously Unpredictable sentences. All words were repetitions. A) All scalp electrode sites. B) Close-up of a central channel (MiPa) and scalp topographies depicting a null effect of prior prediction violation.

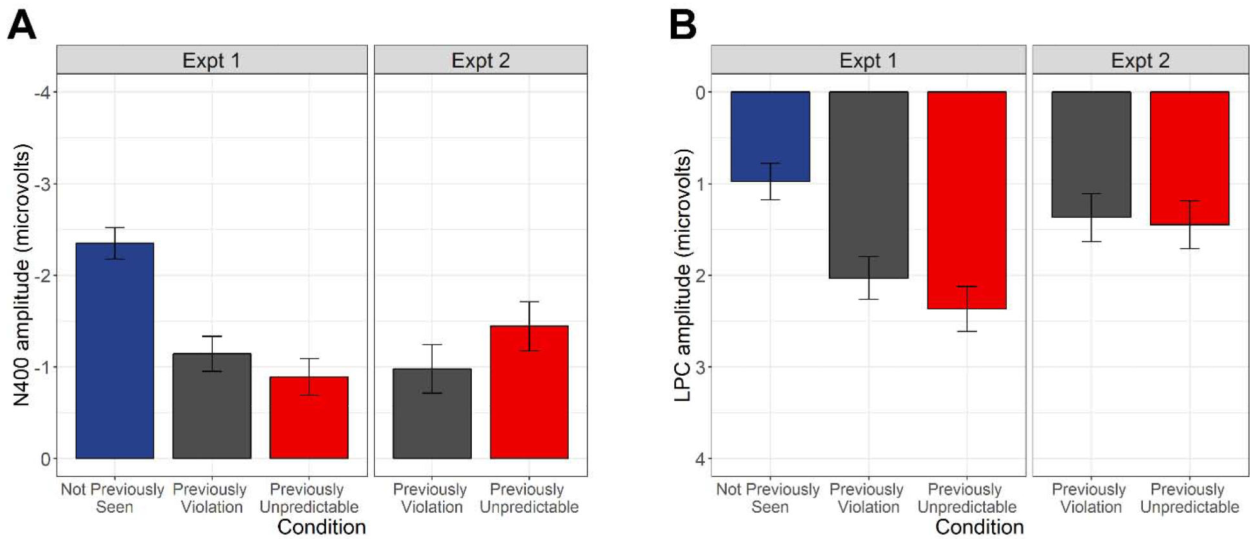

Figure 7.

Mean amplitudes during the N400 (A) and LPC (B) time windows in both experiments. Negative is plotted up. Error bars show the within-subjects standard error around the mean.

Table 1:

Example stimuli from Experiment 1.

	Previously Prediction Violation
First presentation (SC)	Cats love to be scratched behind the collar. (*expected word = ears*).
Filler	The mother of the tall guard had the same accent.
Filler	The lawyer feared that his client was guilty.
Critical sentence (WC)	In the afternoon we started looking for the collar.
	Previously Unpredictable
First presentation (WC)	What caught their attention was something on his collar.
Filler	The mother of the tall guard had the same accent.
Filler	The lawyer feared that his client was guilty.
Critical sentence (WC)	In the afternoon we started looking for the collar.
	Not Previously Seen
Filler	The mother of the tall guard had the same accent.
Filler	The lawyer feared that his client was guilty.
Critical sentence (WC)	In the afternoon we started looking for the collar.

Note. Critical words are underlined. The critical sentence was always weakly constraining (WC), but the conditions differed in terms of what participants had previously seen. If the critical word had previously been seen, it had been shown either in a strongly constraining sentence (SC), where it constituted a prediction violation, or in a weakly constraining sentence.

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Table 2:

Example stimuli from Experiment 2.

	Predictable
Single presentation (SC)	Cats love to be scratched behind the ears.
	Unpredictable
Single presentation (WC)	The baby cried when somebody touched his ears.
	Previously Prediction Violation
First presentation (SC)	Cats love to be scratched behind the collar. (*expected word = ears*).
Filler	The mother of the tall guard had the same accent.
Filler	The lawyer feared that his client was guilty.
Critical sentence (WC)	In the afternoon we started looking for the collar.
	Previously Unpredictable
First presentation (WC)	What caught their attention was something on his collar.
Filler	The mother of the tall guard had the same accent.
Filler	The lawyer feared that his client was guilty.
Critical sentence (WC)	In the afternoon we started looking for the collar.

Note. Critical words are underlined. The critical sentence was always weakly constraining (WC), but the conditions differed in terms of what participants had previously seen. If the critical word had previously been seen, it had been shown either in a strongly constraining sentence (SC), where it constituted a prediction violation, or in a weakly constraining sentence.