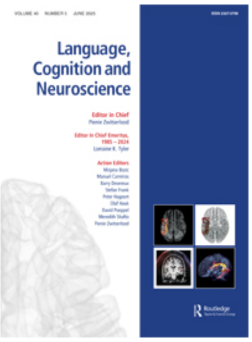

Language, Cognition and Neuroscience

ISSN: 2327-3798 (Print) 2327-3801 (Online) Journal homepage: www.tandfonline.com/journals/plcp21

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LANGUAGE, COGNITION AND NEUROSCIENCE
https://doi.org/10.1080/23273798.2025.2503906

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Contrastive focus accent retroactively modulates memory for focus alternatives: evidence from event-related potentials

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ABSTRACT
Contrastive focus accent in spoken language indicates that alternatives to the focused element are relevant for interpretation. The sentence "Could I have some TEA, please?", with contrastive accent on *tea*, is probably the response to an offer of several alternative beverages. Research shows that contrastive focus accent helps listeners remember such alternatives. We investigated the time-course of and mechanisms behind the effects of contrastive focus accent on memory with a variant of the subsequent memory effect paradigm with event-related potentials (ERPs). The ERP time-locked to a critical word was more positive-going if participants remembered two earlier mentioned alternatives than just one, but only if the critical word had been contrastively accented. This effect further was only observed when the critical word itself was remembered. These findings suggest that contrastive focus marking triggers a reinstatement of the preceding sentence context (retrieval practice) by which these elements are prioritised in memory.

ARTICLE HISTORY
Received 2 July 2024
Accepted 25 April 2025

KEYWORDS
Event-related potentials; subsequent memory effect; retrieval practice; focus alternatives; contrastive accent

1. Introduction

When humans use language, they can mark parts of an utterance as background information or new information. Hence, they can guide a listener towards parts of the utterance that are particularly important, potentially unexpected or surprising. One possibility to do so is by using focus, and in particular, contrastive focus. In (1), the same sentence is uttered, once with prosodically marked focus on *Tamara*, once with prosodically marked focus on *pearls*. Focus is indicated by a subscripted F and accent by capital letters.

(1) (a) $[\text{TAMARA}]_F$ has sold the pearls.
(b) Tamara has sold $[\text{the PEARLS}]_F$.

While both sentences convey the same meaning, they evoke different inferences. In (1a), the speaker wants to emphasise that it was Tamara and not somebody else who sold the pearls. In (1b), the inference is that the pearls were sold and not something else. This is captured in Krifka's (2008) often-cited definition of focus: "Focus indicates the presence of alternatives that are relevant for the interpretation of linguistic expressions" (p. 247).

1.1. Prosodic focus marking and memory for alternatives

Prosodic focus does not only have consequences for online processing and interpretation, but also affects implicit and explicit memory for the focus alternatives: Psycholinguistic studies have found that alternatives to a prosodically focused element are recognised faster in lexical decision studies than in a control condition where the focused element[1] is neutrally accented (Dutch: Braun & Tagliapietra, 2010; English: Husband & Ferreira, 2016; Mandarin Chinese: Yan & Calhoun, 2019), suggesting that focus accent increases the activation of the alternatives' representations in memory.

Certain types of focus marking, in particular the use of a contrastive focus accent, also improve explicit memory for alternatives that were mentioned in a prior discourse. This has been found both with recognition memory tasks (English: Fraundorf et al., 2010; Fraundorf et al., 2013) and with recall (German: Koch & Spalek, 2021; Spalek et al., 2014; Vietnamese: Tjuka et al., 2020), when the critical word is contrastively accented.

Fraundorf et al. (2010) used a recognition memory task in order to investigate the effect of contrastive accent on memory both for a critical word and its

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alternative. They presented participants with utterances containing pairs of alternatives such as (2)

(2) Both the British and the French biologists had been searching Malaysia and Indonesia for the endangered monkeys. Finally, the $[\text{British}]_F$ spotted one of the monkeys in Malaysia and planted a radio tag on it.

The second sentence singled out one of the members of each pair (here: British, Malaysia), using contrastive accent in one of these cases (here: British). In a subsequent memory task, participants had to decide whether a given utterance was true or false. Participants were more accurate in saying that a sentence was correct if it contained an item that had previously been contrastively accented. Participants were also more accurate in saying that a sentence was incorrect if it contained an alternative to a previously contrastively accented item (e.g. The French found one of the monkeys.). Crucially, the beneficial effect of the accent was not found if participants had to judge a sentence with a previously unmentioned element (e.g. The Portuguese found one of the monkeys.). The authors conclude that contrastive accent not only improves encoding of the critical word but it also evokes representations of its alternatives (i.e. a representation of the French NOT finding the monkey.). They refer to this explanation as the contrast account.

Koch and Spalek (2021) investigated the effect of contrastive accent on alternative recall. Consider (3):

(3) Tamara stored pearls, rubies, and sapphires in her safe. She needed some money. She sold the pearls.

Participants who listened to this story and were asked in a later memory test: "What was in the safe initially?", remembered the rubies and sapphires better if *pearls* (the critical word) in the third sentence had been produced with a contrastive focus accent than if it had been produced with a neutral accent. Similar memory benefits for the recall of focus alternatives have been observed in the presence of focus-sensitive particles like *only* or *even* (Spalek et al., 2014).

These examples show that focus marking affects not only implicit memory processes such as lexical decision but also explicit processes such as recall and recognition. However, it is still unclear which mechanisms contribute to this memory benefit for alternatives to prosodically focused elements. The previous studies listed above have only made inferences on memory processes on the bases of recall performance. We propose to use the electroencephalogram (EEG) methodology that will allow us to investigate the neural processes related to the encoding of the critical word while they unfold. This will help answer the question whether the representations of alternatives are strengthened retroactively while the critical word is processed or whether a more salient critical word is better recalled and then serves as a more efficient retrieval cue for the alternatives. The latter assumption would predict that there is a positive correlation between correctly recalled critical words and correctly recalled alternatives. Previous behavioural findings are contradictory: While Tjuka et al. (2020) observed a joint memory benefit for critical words and their alternatives through prosodic focus marking, Koch and Spalek (2021) found that prosodic focus marking improved alternative recall without improving recall of the critical word itself.

Event-related potentials (ERP) are an ideal tool to investigate the online processing of the critical word while it unfolds and to relate this electrophysiological activity to participants' later memory performance for the narrative. Only if the representation of alternatives is strengthened retroactively during the encoding phase of the critical word, would we predict to see a modulation in the ERP elicited by the critical word. If, by contrast, the memory benefit happens during the recall phase, we would not expect to find an effect in the ERP measured while participants listen to the narrative.

ERP activity indicative for successful memory encoding can be studied by segregating ERP waveforms time-locked to stimulus presentation according to whether the event is later remembered or forgotten. This so-called Subsequent Memory Effect (SME) is a powerful tool to explore the neural underpinnings of successful memory formation (see Cohen et al., 2015; Mecklinger & Kamp, 2023; Paller & Wagner, 2002, for reviews). The SME does not reflect a uniform process. Rather, successful memory formation is implemented by multiple processes typically reflected in different subcomponents of the SME. While several studies have explored how prosody affects memory, this is to the best of our knowledge the first study using the SME paradigm to explore the relationship between prosodic focus and memory.

In order to investigate the memory benefit bestowed by focus marking on focus alternatives, we need to determine which aspect of processing an utterance with a focus-marked element gives rise to superior memory for alternatives and how this is reflected in the SME.

A contrastive focus accent in German, sometimes called an L + H* accent, is characterised by a high pitch, with a low starting point, which results in an exaggerated pitch range. In addition, contrastively focused elements are often longer in duration and sometimes also higher in intensity (Baumann et al., 2006;

Baumann et al., 2007). Thus, a contrastive accent is acoustically prominent. Salience is one of the driving factors of the SME. For example, Kamp et al. (2015) presented word lists for recall in which one word stood out due to its emotional valence. A word with negative valence might occur in a list with neutral words or a neutral word in a list with words with positive valence. Recall was improved for words of negative valence. This memory benefit was accompanied by a posterior SME (see Weigl et al., 2020, for a similar finding). If the contrastive focus accent makes the focused word and its alternatives stand out in a way similar to emotionally valenced words, this would be one potential mechanism behind the memory benefit during prosodic focus marking.

1.2. Retroactive memory enhancement

In the present study, however, we are not interested in a memory benefit for the focused word itself but rather in the memory benefit for alternatives for the focused word. To accomplish this, we replicated the study by Koch and Spalek (2021) while recording participants' EEG. Participants listened to spoken narratives that introduced three elements. One of these elements is later repeated (the critical word), either in a focus-marked or in a neutral manner and we segregate ERP activity elicited by the critical word according to how many of the alternatives of the first sentence were remembered. That is, we investigate whether there is a retrospective memory enhancement for the elements from the preceding context sentence initiated by the processing of the focused element. That such retrospective effects can occur has been demonstrated by Anderson et al. (2006). These authors have presented neutral test items for memory, followed by emotional scenes of varying arousal. They found that more arousing scenes are remembered better than less arousing ones. Interestingly, however, processing an emotional scene also improved memory for the previous, neutral scene if the modulating scene was presented 4s (but not after 9s) after the target scene. The authors conclude that processing of an arousing stimulus can affect memory consolidation of an immediately preceding stimulus.

Similar effects of memory enhancement by emotionally arousing events that extend to events preceding the arousing event have been reported in studies on post-learning stress (Cahill et al., 2003), in studies combining a memory task with a fear learning procedure (Dunsmoor et al., 2015; Kalbe & Schwabe, 2022) or in a study on reward motivation (Patil et al., 2016).

While prosody can have strong links to emotion, the contrastive focus accent is not the only type of focus marking that enhances memory for alternatives. The use of a focus-sensitive particle, for example, *only*, has the same effect (Spalek et al., 2014). Therefore, it would be desirable to find a mechanism that can explain the memory enhancement of focus also in those cases where increased arousal seems less likely. Processing focus might cause an attentional boost which has been demonstrated to increase memory performance, too. Broitman and Swallow (2020) presented participants with photographs of faces. These photographs had either an orange or a blue frame. Participants were instructed to react to the presence of a particular frame colour. If participants were later tested on their memory for the faces, memory was improved if the photograph had been a target during encoding, that is, if its frame was of the colour to which participants had to react. It is conceivable that the contrastive focus accent (as well as the addition of a focus-sensitive particle) also has a kind of signalling function (like the colour frame) that causes an attentional boost which improves memory for the contextual information, in our case, the alternatives. However, we believe that the reason why focus retrospectively increases the salience of its alternatives is less arbitrary than the co-occurrence of two unrelated pieces of information. Instead, we think that the reason why alternatives are higher in salience in the presence of a contrastive focus accent has to do with the interpretation of the linguistic utterances. Most theoretical accounts of focus assume that it evokes alternatives (Krifka, 1993; Roberts, 2012; Rooth, 1992; Wagner, 2020). Abstracting away from the theoretical details, focus alternatives can take the position of the focused element such that the resulting utterance is still grammatical and meaningful. Therefore, alternatives often belong to the same semantic category (e.g. fruit, animals, but see Gotzner, 2019; Joerdens et al., 2020, for a demonstration that focus alternatives need not belong to the same category). Thus, a listener encountering a focus-marked element will expect or activate some alternatives. If the activated alternatives have already been provided in the context, this will strengthen their representation. Some theories such as Rooth (1992, 2016) are explicitly anaphoric, with focus as an anaphor and an alternative set its antecedent. According to these theories, when we encounter a focused element, we need to look back to identify the alternative set it stems from. Thus, focus marking might have the effect of making a listener or reader go back over previous parts and reinstate these parts of a narrative.

A related effect is reported by Tullis et al. (2014) using word lists: When participants learn items for later recall, an item that is related to a previously learned item retroactively enhances the recall performance of the earlier item. The authors argue that reminding serves as a kind of retrieval practice that promotes later retrieval. Thus, the enhanced memory for reminded items results from retrieving these items from memory.

1.3. Neurocognitive mechanisms

In the following, we will sketch possible neurocognitive mechanisms that enable the retroactive enhancement of specific memories during contrastive focus marking:

Mecklinger and Kamp (2023) suggest that the SME can be subdivided in three functionally different subcomponents, an early frontal SME reflecting semantic processing, a parietal SME indicative for processes that support the formation of rich and durable memory traces like the reinstatement of intrinsic features of a prior study episode and a late frontal SME signalling the use of elaborate encoding strategies. In the present study we do not intend to distinguish among these subcomponents but rather assume that for the processing of contrastively accentuated focus several of the aforementioned processes might play a role. While the study is not intended to disentangle the components, the time course and topography might be informative about the ones relevant for processing a contrastive focus accent.

1.3.1. The present study

In the present study, we will carry out an SME experiment with the items used in the behavioural study by Koch and Spalek (2021). We investigate whether the distinctive contrastive accent on a critical word influences consolidation of its alternatives in memory.

Specifically, we test the following hypotheses[2]:

(1) We will replicate the behavioural memory benefit for alternatives to a contrastively focused element. That is, we will observe a higher rate of correct recall of alternatives when the focused element bears contrastive accent than when the focused element is neutrally accented.

(2) We expect to find an SME on the critical word which is more pronounced the more alternatives are remembered, that is, a larger SME if two alternatives are remembered compared to one. This effect will be called retrograde SME in the following. Given the findings from previous SME studies, we expect this effect to be sustained and broadly distributed at frontal and parietal electrodes.

(3) Most importantly, if contrastive focus accent enhances the encoding of the alternatives (what has been shown behaviourally), we expect the retrograde SME described in 2 to be larger in the case of contrastive focus accent than in the case of neutral focus accent, that is, we expect an interaction of memory (for the alternatives) and accent.

(4) If the memory benefit is due to the fact that contrastive focus accent improves memory for the critical word itself, we should observe better recall of critical words in the contrastive focus condition than in the neutral condition.

(5) If the critical word serves as a retrieval cue, we would predict an effect of recall of the critical word on alternative recall, both behaviourally and in the SME. If, in addition, this interaction depends on the presence of a contrastive focus accent, we would expect to see a three-way interaction of accent by memory for the critical word by memory for the alternatives.

In addition to the primary research questions and hypotheses, we will also investigate the SME effect for the focused element itself. Here we test the following hypothesis:

(6) We will observe a subsequent memory effect for the critical word based on whether or not it is recalled, since this is actually closer to the common SME paradigms (the event-related potential on an item during encoding is indicative of this item's recall).

2. Methods

The experimental methods, hypotheses and planned analyses were preregistered on the platform AsPredicted (https://aspredicted.org/rn2x-5knm.pdf).[3]

2.1. Participants

Fifty students between 18 and 35 years participated, 26 at the Universität des Saarlandes in Saarbrücken (9 men, 17 women) and 24 (6 men, 17 women) at the Humboldt-Universität zu Berlin. The experiment was originally carried out at the Humboldt-Universität zu Berlin. Data acquisition had to be put on hold due to Covid-19 restrictions. By the time data acquisition could be resumed, the first author had moved and could not use EEG lab facilities in Berlin any more. It was therefore decided to collect the second half of the data in Saarbrücken under identical recording conditions. We added "Lab" as an additional factor in the ERP analyses to compare performance between labs.

Participants had normal or corrected-to-normal vision and did not report any hearing loss, language disorders or neurological disorders. All participants were righthanded and native German speakers. Participants received course credits or a monetary compensation of 8€ per hour. (Due to the selection criteria described below, the final sample consisted of 31 participants, 14 from Berlin and 17 from Saarbrücken). In the preregistration of the method, we had set down the following stopping criterion: After data acquisition of 48 participants, we would analyse the data and either stop or acquire 24 more participants if there was a trend in the data that was not yet significant.

The procedure was approved by the ethics committee of the Deutsche Gesellschaft für Sprachwissenschaft (German Linguistic Society, https://dgfs.de/de/inhalt/ueber/ethikkommission.html). Participants provided written informed consent and were instructed that they could withdraw from the study at any time.

2.2. Materials

We used 80 spoken short stories containing two context sentences and a critical sentence (Example (4), stimuli were the same as in Koch & Spalek, 2021, and are available on OSF: https://osf.io/txq5r/).

(4)
Context sentence 1:
Tamara lagerte in ihrem Tresor Perlen, Rubine und Saphire.
(Tamara stored pearls, rubies and sapphires in her safe).
Context sentence 2:
Sie benötigte Geld.
(She needed some money).
Critical sentence:
Sie hat die Perlen/ die PERLEN verkauft.
(She sold the pearls/ the PEARLS.)

The first context sentence introduced a person, a setting (e.g. *safe*) and a set of three contextually-related elements (e.g. *pearls*, *rubies*, *sapphires*). The second context sentence continued the story and, in most cases, indicated a choice or selection to be made by the person. The critical third sentence mentioned one of the three elements from the first sentence again (we call this the *critical word*). Across items, the critical word in the third sentence was equally often the first, second, or third element from the first context sentence. Two versions were constructed for each critical sentence: (a) a control condition with neutral focus (H + !H* pitch accent) and (b) a version with a contrastive focus (L + H*pitch accent) on the critical word. The stories were spoken in normal speech rate, that is, participants listened to connected speech instead of being presented with the word-by-word presentation typically used in visual EEG studies on language. More details on the stories can be found in Koch and Spalek (2021).

Memory items during the test phase for all experimental stories were the three words from the first sentence. For 16 additional filler stories, memory was tested for other aspects of the story. The audio files were cross-spliced such that the contrastively and the neutrally accented critical word occurred in the same acoustic context. For each story, we determined the onset and the offset of each of the three words (Perlen, Rubine, Saphire in the example above) in the first sentence and the onset and offset of the critical word (Perlen/PERLEN) in the third sentence.

2.3. Procedure

Participants read and signed the consent form and filled in the German brief version of a questionnaire assessing autistic traits (AQ-K, Freitag et al., 2007; original: ASQ, Baron-Cohen et al., 2001). The analysis of the AQ-K will not be part of the present report.

Preparation of the EEG cap took about 35–40 min. Afterwards, participants were seated in an electrically-shielded, sound-attenuating cabin. Visual stimuli were presented on a 24 inch-monitor with a resolution of 1980 × 1080 pixel, a refresh rate of 60 Hz and 8-bit colour depth. Audio stimuli were presented via speakers. Participants' responses were recorded with a microphone. The experiment was programmed with Presentation (Version 23.0, Neurobehavioural Systems).

Several instruction screens explained the procedure. Participants first carried out a practice block consisting of six stories. After answering any questions participants still had concerning the procedure, the main experiment started. The main experiment consisted of eight blocks with ten stories each. Each block contained a learning phase, during which the stories were presented, and a cue-based recall phase during which participants verbally answered questions about the stories (see below for details). At the end of each block, participants carried out a backwards counting task in order to briefly distract them. For example, they were instructed to count backwards from 80 in steps of 8 or from 30 in steps of 3. Each block lasted about five minutes and the entire experiment lasted between 40 and 50 min.

2.3.1. Learning phase

Each block consisted of eight critical stories and two filler stories. Half of the items within a block were presented with contrastive focus accent and half with neutral focus accent. Within a block, a semantic category (e.g. *tools*) did not occur more than once. Participants were presented with one of eight experimental lists. Two base lists were created such that a critical word that was presented with contrastive focus accent in base list A was presented with neutral accent in base list B and vice versa. Four different orders were created for each of these base lists.

Figure 1 is a schematic illustration of a single trial during the learning phase. Each trial started with a fixation cross centrally presented for 500 ms. Each sentence of a story was presented auditorily, while the fixation cross stayed on the screen. Between sentences, there was a pause of 500 ms. The trial ended with a silent interval during which participants were encouraged to blink (while they had been instructed to avoid blinking during the presentation of the story). After ten trials, a learning phase ended and a recall phase started.

2.3.2. Recall phase

Each recall phase started with the message "Jetzt erfolgt die Abfrage dieses Blocks." ("Recall for this block is about to start.") presented for 2000 ms. Each recall block consisted of ten questions, that is, one question per story from the learning block. Questions were presented in black on a white background in Arial font, size 28. The order of questions was the same as the order of stories. In this way, we ensured that the same amount of linguistic material occurred between a story and its corresponding question. For critical stories, participants were given the location as a recall cue and had to remember the three elements from the first sentence (e.g. "Welche Kostbarkeiten befanden sich zunächst im Tresor?"/ "Which treasures were there in the safe at first?"). For filler items, participants had to answer questions about the action, the job or the gender of the person or the element focused in the third question (e.g. "Was the person in the pharmacy a man or a woman?", "What did Regina do in the plane?"). The fillers were presented in order to prevent participants from just memorising the three elements from the first sentence. At the beginning of each trial in the test phase, the question was presented visually for 3000 ms on the screen. It was followed by a series of hashmarks which stayed on the screen for a maximum of 20 s. Participants gave spoken responses that were recorded on file. Participants were instructed to respond while the hashmarks were on the screen. In order to avoid losing information if participants started speaking while the question was still on the screen, the recording actually started with the presentation of the question. If participants were sure that they had given an exhaustive response or that they would not remember anything else, they could jump to the next trial by pressing the space bar. In order to distinguish between genuinely forgotten information and recording failures, we asked participants to say out loud: "I don't remember" if they could not remember anything. After ten recall trials, participants were instructed to count backwards in ten steps, for example: "Count backwards from forty in steps of four". After this distractor task, the next learning phase started.

2.4. EEG recording and data processing

In both labs, the electroencephalogram (EEG) was recorded with Brain Vision Recorder (Version 1.21.0102, Brain Products GmbH, Gilching, Germany) from scalp electrodes (Fp1/2, F3/4, FC1/2, FC5/6, T7/8, C3/4, Cz, CP1/2, P7/8, P3/4, Pz, O1/2, Oz, PO9/10, each referenced to the left mastoid; one additional right mastoid electrode and six additional electro-oculogram electrodes, Fz served as ground electrode; EasyCap GmBH, Herrsching, Germany). Since active electrodes were used, impedances below 25 kΩ were considered sufficient. The EEG was amplified (band-pass filtered at 0.016–250 Hz) and digitised at 1000 Hz.

The EEG data were processed offline with the software EEGlab (Delorme & Makeig, 2004; Version 2022.1) and ERPlab (Lopez-Calderon & Luck, 2014; Version 8.20).

After re-referencing to the average of the left and right mastoid electrodes, data were filtered with a 0.5 Hz highpass, 30 Hz lowpass and a 50 Hz Parks-McClellan notch filter. Ocular artifacts were corrected using independent component analysis (ICA). Single-trial waveforms (starting 200 ms before the onset of the critical word and continuing for 800 ms after the onset) were scanned for artifacts. All segments with an amplitude exceeding ±100 µV, a maximal difference of 150 µV within a 200 ms time window or a voltage jump exceeding 30 µV/ms or very little activity (±0.2 µV during 200 ms) were rejected. On average, 8.4% of the segments were rejected.

Two independent annotators listened to the recordings and noted for each word whether it was remembered or forgotten. If participants mentioned a synonym (e.g. "Möhre" for "Karotte", both of which are regional variants of *carrot*) or a hyponym (e.g. "Halskette" for "Kette", where *Kette* is the German word for *necklace* and *Hals* – *neck* – further specifies the place) instead of a target word, we counted this as a correct response. These cases amounted to 1.4% of all correctly recalled alternatives. Hyperonyms (that is, "Schmuck" (jewellery) for "Kette" (necklace)) were not counted as correct responses. Annotations from both annotators were compared and discrepancies resolved by the first author.

As outlined in the Introduction part, in the original analysis plan, we had intended to examine retrograde SMEs elicited by the critical word for the remembered alternatives. To this end, we wanted to compare the EEG response for "no remembered alternatives", "one remembered alternative" and "two remembered

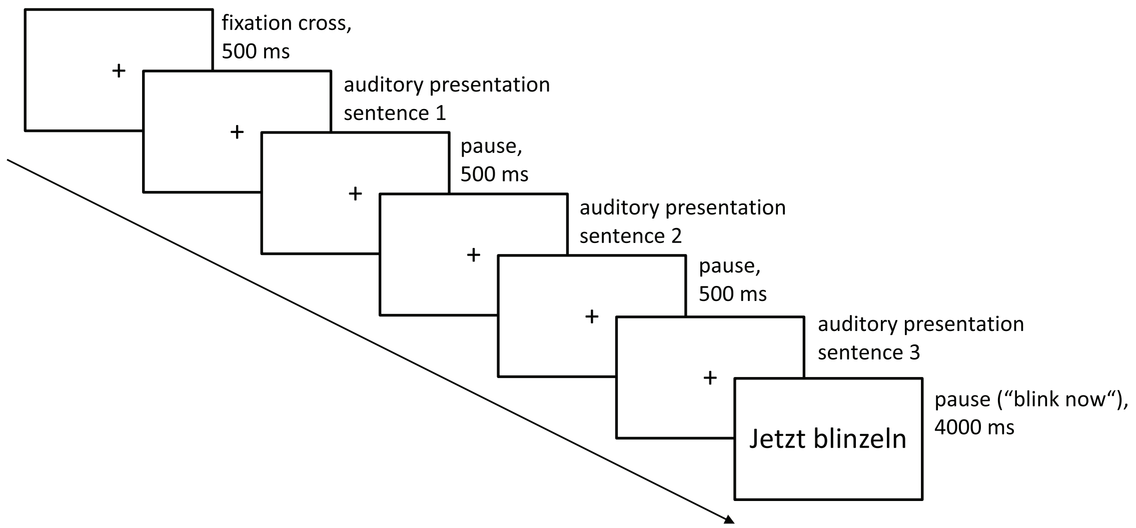

Figure 1. Presentation of one trial during the learning phase.

alternatives", both for contrastive focus and for non-contrastive focus. However, it turned out that participants either showed very good memory performance, having many observations for one or two remembered alternatives and very few or none for no remembered alternatives. Or participants showed worse memory performance, having many observations for no or one remembered alternative and very few or none for two remembered alternatives. Since we wanted to include at least five artifact-free trials per participant and condition for the ERP analysis, we decided to restrict our comparisons to one vs. two remembered alternatives for each focus condition. Thirty-one participants (17 from Saarbrücken and 14 from Berlin, 22 women and 9 men) fulfilled these requirements. The mean and range of trial numbers per condition were as following: $M = 9$, range 5–14 (contrastive focus, 1 alternative remembered); $M = 16$, range 5–24 (contrastive focus, 2 alternatives remembered); $M = 9$, range 5–16 (neutral focus, 1 alternative remembered); $M = 15$, range 6–23 (neutral focus, 2 alternatives remembered). Grand average waveforms were low-pass filtered at 10 Hz for illustration purposes only.

2.5. Statistical analyses

2.5.1. Behavioural data

Statistical analyses were carried out using the statistical computing environment R (version 4.0.0). The behavioural data were analysed with logistic mixed models (GLMER) with the lme4 package (version 1.1–23).

2.5.1.1. Alternatives. We modelled whether or not an alternative was remembered based on the FOCUS condition (neutral focus vs. contrastive focus). FOCUS was sum-coded. We added centred TRIAL number as a predictor. Random effects for participant, word and item were also included.[4]

2.5.1.2. Critical word. In the analysis modelling recall of the critical word itself, we dropped the random effect for word, since in this case, only one relevant word occurred in a given item.

2.5.1.3. Critical word as recall cue. We repeated the analysis illustrated in 2.5.1.1, adding the information whether or not the critical word was recalled as predictor.

2.5.2. Event-related potentials

ERP mean amplitudes were analysed in the 300–700 ms window after the onset of the focused word. This time interval was chosen because similar time intervals were used in prior SME studies (Duarte et al., 2004; Griffin et al., 2013; Guo et al., 2006; Höltje et al., 2019) and because in this time interval, the SME subcomponents were expected to be largest. The electrode montage consists of 2×4 electrodes that cover anterior (F3, F4, FC1, FC2) and posterior (CP1, CP2, P3, P4) brain regions. The data were analysed using repeated measures ANOVAs with the afex package (version 1.1–1).

2.5.2.1. Alternatives. The analysis contained the within-subject factors MEMORY (1 vs. 2 alternatives remembered), FOCUS (contrastive accent vs. neutral accent), ANTPOS (anterior vs. posterior electrodes), LATERALITY (left vs. right) and the between-subject factor LAB (Berlin vs. Saarbrücken). Greenhouse-Geisser corrected degrees of

Table 1. Percentage alternative recall.

Focus	Critical word forgotten	Critical word remembered
Contrastive accent	35.78	73.64
Neutral accent	35.56	73.13

freedom and *p*-values are reported whenever the assumption of sphericity was violated. Effect sizes will be reported as partial eta^2. Significant effects were decomposed using lower-level ANOVAs. For reasons of clarity, only effects involving the factors of interest (MEMORY and FOCUS) will be reported.

2.5.2.2. Critical word. The analysis was virtually identically to the one in 2.5.2.1, with the one exception that the factor MEMORY (i.e. recall of alternatives) was now replaced by CRITICAL WORD REMEMBERED, distinguishing whether the critical word was remembered or not.

2.5.2.3. Critical word as recall cue. We carried out a single-trial ERP analysis by extracting the mean voltages 300–700 ms after the onset of the critical word for each trial. This allowed us to analyse the data with a linear mixed effects model with single trial voltage as dependent variable and MEMORY (1 vs. 2 alternatives remembered), FOCUS (contrastive vs. neutral accent), CRITICAL WORD REMEMBERED (yes vs. no), ANTPOS (anterior vs. posterior), and LATERALITY (left vs. right) as independent variables and participant and item as random factors. All dependent variables were sum-coded.

A number of secondary analyses were suggested in the preregistration. None of them yielded significant effects and, therefore, they will not be presented here.

3. Results

3.1. Behavioural results

3.1.1. Filler stories

67% (range: 44−94%) of the filler stories were answered correctly. In the preregistration, we had formulated two exclusion criteria: The first one required participants to have more than 75% correct answers which would have resulted in the loss of many datasets. The second criterion was only to be used if the questions proved unexpectedly difficult: In this case, we wanted to exclude all datasets in which the accuracy rate for fillers was more than 2 SD below the average. This resulted in a negative value of correctly answered filler stories, so, eventually, we kept all datasets. Even the worst participant answered 7 out of 16 filler questions correctly, suggesting that they had paid at least some attention to aspects of the story other than the three critical elements.

3.1.2. Experimental Items

3.1.2.1. Alternatives (Hypothesis 1). Recall performance was not affected by FOCUS accent at the group level, with almost identical recall performance for alternatives in the contrastive accent condition (m = 65.3%, sd = 47.61) and the neutral accent condition (m = 64.87%, sd = 47.75). This was confirmed by a null effect of FOCUS in the GLMER ($\beta = -0.003$, $z = -0.07$, $p = .94$). Participants showed a learning effect, though, such that their performance improved with increasing TRIAL number ($\beta = 0.016$, $z = 9.956$, $p < .001$). The learning effect was not affected by FOCUS, as reflected in a non-significant interaction ($\beta = 0.001$, $z = 0.748$, $p = .45$).

3.1.2.2. Critical word (Hypothesis 4). Recall performance was almost identical for the critical word with contrastive focus accent (m = 77.98%, sd = 41.46) and neutral accent (78.02%, sd = 41.42). This was confirmed by a null effect of FOCUS in the GLMER ($\beta = 0.008$, $z = 0.14$, $p = .89$). In contrast to the analysis on alternative recall, no learning effect was observed ($\beta = 0.002$, $z = 0.97$, $p = .34$).

3.1.3. Post-hoc analyses

The following analyses were not part of the pre-registration. We carried them out in order to gain a closer understanding of the null effect of focus condition on memory for alternatives (3.1.3.1) and to investigate whether recalling the critical word might affect alternative recall, too (3.1.3.2, 3.1.3.3).

3.1.3.1. Memory performance in first experimental block. In order to explore the possibility that participants develop strategies throughout the experiment, we looked at the first block separately. Here, participants remembered 46% of the alternatives correctly in the neutral accent condition and 49% in the contrastive focus accent condition. Given that the first block only comprises 8 experimental items, this effect was not significant in a GLMER with FOCUS as fixed effect and random intercepts for participant, item and word ($\beta = -0.088$, $z = -0.853$, $p = .39$).[5]

3.1.3.2. Critical word as recall cue (Hypothesis 5). In this analysis, we tested whether remembering the critical word improves memory for the alternatives. Table 1 presents alternative recall split by the FOCUS condition and CRITICAL WORD REMEMBERED:

While the (negligible) effect of FOCUS is not affected by memory for the critical word, remembering the critical word is highly predictive of alternative recall. When we add memory for the critical word as a predictor to the analysis reported in 3.1.2.1, this turns out to be a highly significant predictor of alternative recall ($\beta = 0.762$, $z = 16.62$, $p < .001$), but does not interact with FOCUS ($\beta = 0.005$, $z = 0.11$, $p = .91$).

3.1.3.3. Association strength between the critical word and its alternatives. This analysis is a follow-up to the previous one as it investigates the possibility that the effectiveness of the critical word as recall cue is modulated by the strength of the association between critical word and alternatives. In order to test whether alternatives that are strongly related to the critical word have a larger memory benefit than those that are only loosely associated with it, we extracted the pairwise cosine similarities between an alternative and the corresponding critical word, using the semantic space dewak100k_lsa and the R package LSAfun by Günther (2023). Out of the 128 alternatives used, we were able to get the association strength for 104 alternatives. With this reduced data set, we computed the correlation between the average recall percentage for a given alternative and its association strength to the critical word, separately for focus accent and neutral accent. Association strength did not correlate significantly with alternative recall ($r = 0.05$, $p = .59$; $r = 0.03$, $p = .75$, respectively).

3.2. ERP results

3.2.1. Alternative recall (Hypotheses 2 and 3)

Figure 2 shows the grand average ERP waveforms elicited by the number of remembered alternatives (1 or 2) in the two FOCUS conditions (contrastive vs. neutral). The right part of the figure shows the topographic distribution of the (2 minus 1 alternatives remembered) difference waveforms in the 300–700 ms time window. The ERPs were computed for the critical words, which were embedded in a connected speech signal. The jittered onset of the eliciting word in the speech signal may have smeared the early sensory ERP components, so that no clearly discernible early components were visible in the averaged waveforms.

As apparent from Figure 2, in the contrastive focus condition the ERPs were more positive going when participants later remembered two than just one alternative. This effect started around 250 ms, extended for several hundred milliseconds and was slightly larger at left than at right hemisphere recording sites. In its temporal and topographical characteristics this retrograde effect resembles known SMEs, that is, the contrast between subsequently remembered and forgotten items. Notably, this effect was virtually absent in the neutral focus condition.

These observations were confirmed by a series of statistical analyses.

An ANOVA including the within-subject factors MEMORY (1 vs. 2 alternatives), FOCUS (contrastive vs. neutral accent), ANTPOS (anterior vs. posterior), and LATERALITY (left vs. right) and the between-subjects factor LAB (Berlin vs. Saarbrücken) yielded a marginally significant effect of MEMORY, $F(1,29) = 4.11$, $p = .052$, $\eta_p^2 = .12$. A significant interaction was found between FOCUS and ANTPOS, $F(1,29) = 6.38$, $p < .05$, $\eta_p^2 = .18$. Most importantly for our research question, we observed a critical interaction of MEMORY, FOCUS and LATERALITY, $F(1,29) = 6.69$, $p < .05$, $\eta_p^2 = .19$. There was no main effect of LAB nor did it affect the relevant MEMORY by FOCUS interaction (all $ps > .10$), but it participated in a three-way interaction with MEMORY and ANTPOS, $F(1,29) = 8.70$, $p < .01$, $\eta_p^2 = .23$.

We first followed up on this three-way interaction with LAB, by analysing the two-way interaction of MEMORY and ANTPOS separately for Berlin and Saarbrücken. While for the data collected in Saarbrücken, a marginally significant main effect for MEMORY was found, $F(1,16) = 4.13$, $p = .059$, $\eta_p^2 = .21$, for the data collected in Berlin, we observed an interaction of MEMORY and ANTPOS, $F(1,13) = 9.86$, $p < .01$, $\eta_p^2 = .43$, with a larger memory effect at posterior sites ($\eta_p^2 = .18$; anterior: $\eta_p^2 = .002$). Still, the crucial interaction of MEMORY and FOCUS was not different between the labs, $F(1,29) = 0.07$, $p = 0.80$, $\eta_p^2 = .002$.

To follow up on the significant MEMORY by FOCUS by LATERALITY interaction, the mean amplitudes were analysed separately for both hemispheres.

3.2.1.1. Focus by memory interaction at left hemisphere recordings. We observed a marginally significant main effect of MEMORY, $F(1,29) = 3.9$, $p = .058$, $\eta_p^2 = .12$, and the crucial interaction of MEMORY by FOCUS, $F(1,29) = 4.47$, $p < .05$, $\eta_p^2 = .13$. Looking at the two levels of FOCUS separately, we observed the following: For contrastive focus accent, there was a significant main effect of MEMORY, $F(1,29) = 10.92$, $p < .01$, $\eta_p^2 = .27$, while for neutral accent, there was no such effect ($F < 1$).

3.2.1.2. Focus by memory interaction at right hemisphere recordings. We observed a significant main effect of MEMORY, $F(1,29) = 4.70$, $p < .05$, $\eta_p^2 = .14$, but the crucial interaction of MEMORY by FOCUS was not significant in the right hemisphere ($F < 1$).

3.2.2. Critical word (Hypothesis 6)

We investigated the ERPs elicited by the critical word, dependent on whether or not participants remembered it.

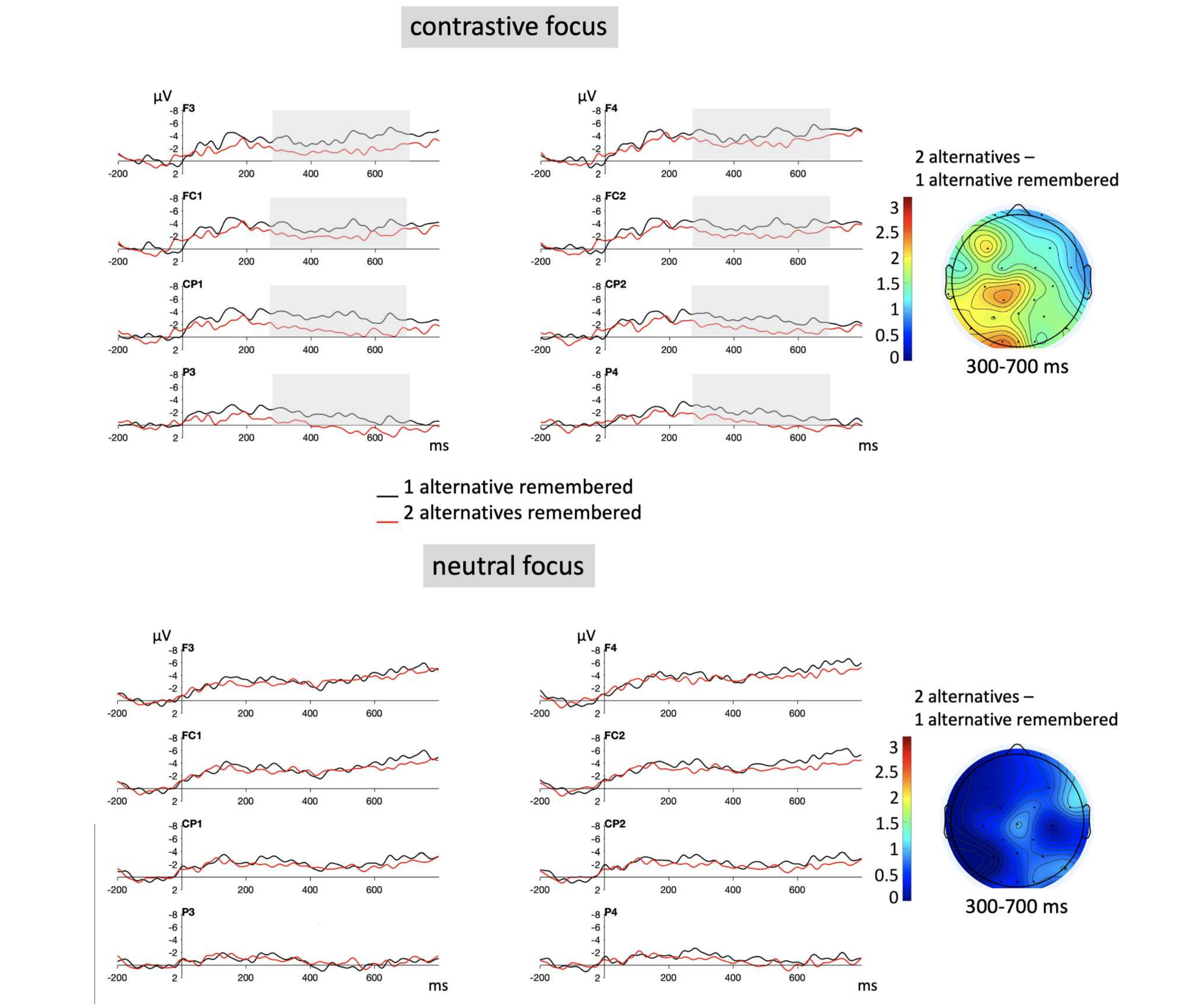

Figure 2. ERP waveforms for 1 or 2 subsequently remembered alternatives from the first sentence, measured at the contrastively accented critical word (upper panel) and at the neutrally accented critical word (lower panel). The shaded area shows the significant difference in the critical time window. Average topographies for the differences between 2 and 1 remembered alternatives are shown in the 300-700 ms time window.

Figure 3 shows that participants' ERP was more positive going when they remembered the critical word compared to when they did not. In its temporal and topographical characteristics this SME resembles the retrograde SMEs illustrated in Figure 2, albeit it is less left lateralised and less posteriorily distributed than the retrograde SME. Notably, in contrast to the SME for alternatives, the SME for the critical word itself does not seem to be affected by the FOCUS condition.

These observations were confirmed by a series of statistical analyses. An ANOVA including the within-subject factors MEMORY (remembered vs. forgotten), FOCUS (contrastive vs. neutral accent), ANTPOS (anterior vs. posterior), and LATERALITY (left vs. right) and the between-subjects factor LAB (Berlin vs. Saarbrücken) yielded a significant effect of MEMORY, $F(1,29) = 7.02$, $p < .05$, $\eta_p^2 = .12$. There was no main effect of FOCUS,[6] no interaction between MEMORY and FOCUS and also no interaction of LATERALITY, MEMORY and FOCUS like the one we had observed for alternative memory (all $ps > .50$). There was no main effect of LAB ($p > .07$) nor did it affect the critical MEMORY and FOCUS interaction ($p > .10$), but it participated in a four-way interaction with MEMORY, ANTPOS and LATERALITY, $F(1,29) = 6.46$, $p < .05$, $\eta_p^2 = .18$.

We followed up on this four-way interaction with LAB by analysing the three-way interaction of MEMORY, ANTPOS and LATERALITY separately for Berlin and Saarbrücken. While for the data collected in Saarbrücken, a significant main effect for MEMORY was found, $F(1,16) = 11.02$, $p = .01$, $\eta_p^2 = .41$, for the data collected in Berlin, this

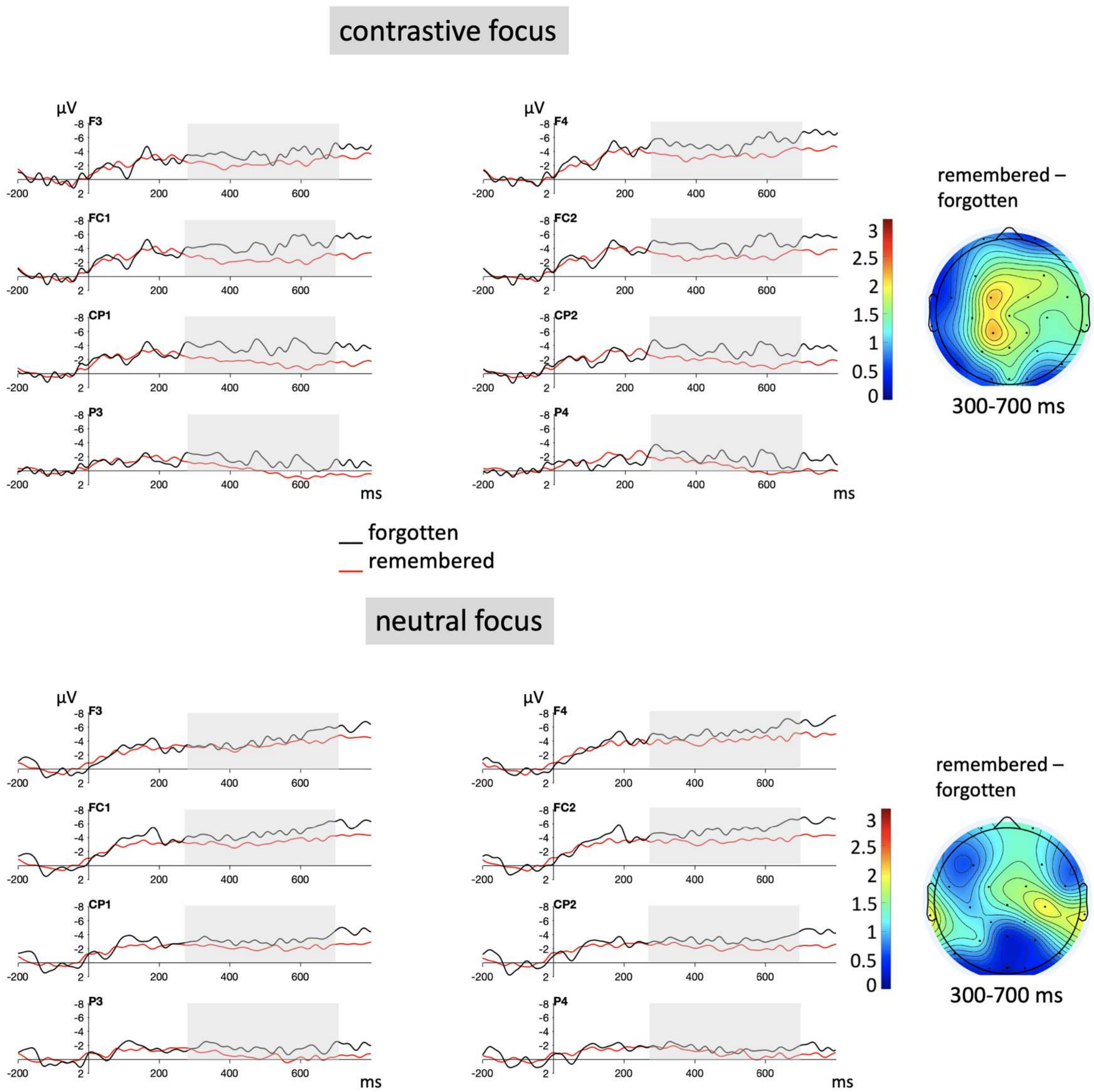

Figure 3. ERP waveforms for the subsequently remembered or forgotten critical word, measured at the contrastively accented critical word (upper panel) and at the neutrally accented critical word (lower panel). The shaded area shows the significant difference in the critical time window. Average topographies for the differences between remembered and forgotten critical word are shown in the 300–700 ms time window.

effect was not significant, $F(1,13) < 1$. Instead, we observed an interaction of MEMORY, ANTPOS and LATERALITY, $F(1,13) = 5.62$, $p < .05$, $\eta_p^2 = .30$. Further resolving this interaction, we observed a marginally significant MEMORY and LATERALITY interaction at posterior sites ($F(1,13) = 4.34$, $p = 0.58$, $\eta_p^2 = .25$). Further resolving this interaction by laterality did not yield significant effects of MEMORY on either hemisphere (all $ps > .25$). This suggests, that as for the analysis of the retrograde SME, the topography of the SME for the critical words differed slightly between the two labs.

3.2.3. Post-hoc analyses

The following analyses were not part of the pre-registration. We carried them out in order to gain a closer understanding of the precise mechanisms underlying the encoding and retrieval of alternatives. In particular, we wanted to address the hypothesis that any memory benefit (which we did not observe behaviourally) might not be due to effects during encoding, but rather to effects during recall.

3.2.3.1. Single trial analysis (Hypothesis 5). As in the analysis of the behavioural data in 3.1.3.2, we wanted to investigate whether remembering the critical word during the recall phase was correlated with the SME for alternative recall. In order to do so, we extracted the mean voltages 300–700 ms after the onset of the focused word for each trial. As a sanity check, we first report the findings of a linear mixed effects analysis with single trial voltages as dependent variable, MEMORY (1 vs. 2 alternatives), FOCUS (contrastive focus accent vs. neutral accent), ANTPOS (anterior vs. posterior) and LATERALITY (left vs. right) as independent variables and participant and item as random factors. We observed a significant effect of MEMORY ($\beta = -0.513$, $t = -5.12$, $p < .001$). The interaction of MEMORY and FOCUS was highly significant ($\beta = 0.380$, $t = 4.02$, $p < .001$), replicating the result from the ANOVA on amplitudes averaged over participants (even though there the interaction of MEMORY and FOCUS was embedded in a three-way interaction of LATERALITY, MEMORY, and FOCUS). None of the other two-way, three-way or four-way interactions was significant.

However, the main reason for this analysis was that it allowed us to model on a trial-by-trial basis the effects of MEMORY FOR THE CRITICAL WORD for memory for the alternatives. Adding this information as an additional predictor to the linear mixed effects model, we observed a significant effect of MEMORY ($\beta = -0.612$, $t = -4.38$, $p < .001$), and a significant effect of FOCUS ($\beta = 0.522$, $t = 3.87$, $p < .001$). The interaction of MEMORY and FOCUS was no longer significant ($\beta = 0.189$, $t = 1.34$, $p = .21$), instead, we observed a significant interaction of FOCUS and MEMORY FOR THE CRITICAL WORD ($\beta = 0.936$, $t = 6.91$, $p < .001$). None of the other higher-order interactions was significant.

Figure 4 shows the effects of FOCUS and MEMORY separately for those trials in which participants later remembered the critical word and those trials in which they had forgotten the critical word.

Given the interaction of MEMORY FOR THE CRITICAL WORD and FOCUS, we analysed the single trial voltages separately for the CRITICAL WORD FORGOTTEN and CRITICAL WORD REMEMBERED. For CRITICAL WORD FORGOTTEN, there was only a significant main effect of FOCUS ($\beta = 1.772$, $t = 6.68$, $p < .001$). The effect of MEMORY for the alternatives ($\beta = -0.538$, $t = -1.83$, $p = .07$) was not significant and neither was the interaction with FOCUS ($\beta = -0.328$, $t = -1.24$, $p = .24$).

For CRITICAL WORD REMEMBERED, we observed a main effect of MEMORY for the alternatives ($\beta = -0.466$, $t = -4.26$, $p < .001$), a significant effect of FOCUS ($\beta = -0.415$, $t = -4.08$, $p < .001$) and a significant interaction of MEMORY for the alternatives and FOCUS ($\beta = 0.278$, $t = 2.69$, $p < .01$).

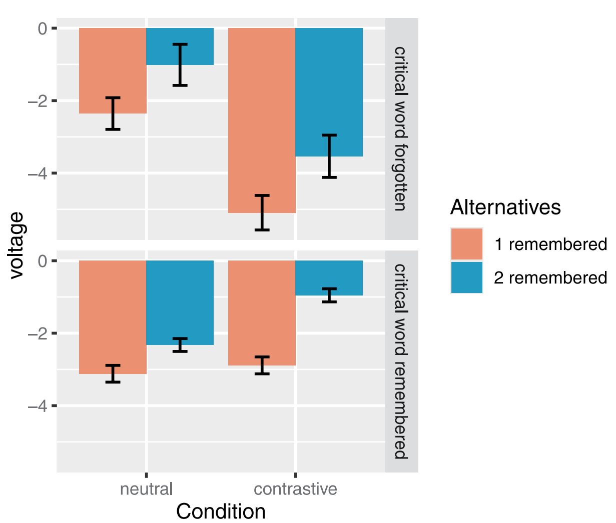

Figure 4. Voltage changes as a function of MEMORY, FOCUS, MEMORY FOR THE CRITICAL WORD, error bars indicate the standard error of the mean.

4. General discussion

In order to advance our understanding of how linguistic focus improves memory for focus alternatives, we investigated the online processing of a critical word with ERP SMEs, linking the ERP to the number of correctly recalled alternatives. Participants listened to stories that introduced three elements. One of these was later repeated (critical word), using either a neutral accent or contrastive focus accent. After a block of ten of these stories, participants were asked recall questions. We investigated the following six hypotheses: (1) We expected to replicate the behavioural memory benefit for alternatives to a contrastively focused element. (2) We expected to find a retrograde SME elicited by the critical word, that is more pronounced the more alternatives are remembered. (3) We expected this retrograde SME to be larger in the case of contrastive focus accent than in the case of neutral focus accent. If the effect in (3) is due to the fact that the critical word is encoded better when it is presented with a contrastive focus accent and later serves as a retrieval cue for the alternatives, we expected to see better recall for the critical word in the contrastive focus accent condition (4) and an increase of alternative recall for correctly recalled critical words (5). (6) We expected to observe an SME for the critical word itself.

4.1. (Non-) replication of behavioural memory benefit

Hypothesis 1 was not confirmed as no memory benefit was observed behaviourally. One account for the absence of a memory benefit in the focus condition pertains to the experimental design of our study. The experiment entailed eight study-test blocks each consisting of ten stories. The repeated presentation of recall blocks with one question per story may have encouraged the intentional learning of the three words irrespective of whether the critical word was spoken with a contrastive or a neutral focus. This repeated use of study test blocks may have clouded memory benefits due to focus marking, in particular as we used fewer filler items than in the behavioural study by Koch and Spalek (2021) in order to increase the number of observations in the EEG. While not significant, descriptive data show a memory benefit in the expected direction, with 46% of the alternatives recalled for neutral focus marking and 49% of the alternatives recall after contrastive focus marking in the very first block of the experiment. Consistent with the view that repeated memory testing may have clouded memory benefits of focus marking, for all later blocks, recall performance in the two conditions was almost indistinguishable.

In addition, there is evidence for individual differences in how well intonational information is integrated with the linguistic content (e.g. Hung & Cheng, 2014; Schirmer et al., 2002; Schirmer et al., 2004; Schirmer et al., 2005; Wildgruber et al., 2002). With regard to focus, Cangemi et al. (2015) have demonstrated that individual listeners vary in how reliably they can decode focus information from different speakers. Thus, it is well possible that only a subgroup of participants will benefit from focus accent. The other participants could either not be sensitive to the accent or they could interpret the critical word as focus in both contexts. Cohan (2001) suggests that focus is a result of the presence of alternatives, and contrastive focus is licensed if there is at least one explicitly mentioned alternative in the previous context. In our stimuli, we presented two alternatives in the first sentence, which makes it natural to interpret the critical word in the third sentence as focus. For participants who did this, we might expect memory benefits from focus in both conditions, leading to a null result in the comparison. However, we do not yet know a principled way to extract these participants from the overall sample with a criterion that is orthogonal to the observed data.

One possible way to address this null finding in future research would be the use of a different paradigm. The study by Fraundorf et al. (2010) might be a good place to start since participants will be less able to predict which of the two times two alternatives will be relevant during recall. Also, these authors presented all stimuli in one block before testing recognition memory which would have made it impossible for participants to use memorisation strategies tailor-made for the recall task. Another possibility would be to keep the present paradigm but use more fillers. While the filler to experimental items ratio in the present study (16:64) did not prevent the use of strategies, the ratio used in Koch and Spalek (35:45) did.

Other labs have also found that behavioural effects of retrograde memory enhancement are difficult to replicate. Kalbe and Schwabe (2022) suggest that it matters whether items are remembered with high or low confidence. Retrograde memory effects were only observed for those items that were remembered with high confidence.

To sum up, there are a variety of reasons why we could not replicate the original behavioural finding. Importantly, we do not think that the behavioural null results preclude any effects of memory on the ERP data, because behavioural performance is the end-product of a process that might include several different sub-processes and as such, remains a black-box. ERP data time-locked to the critical word allow us to focus on one of these sub-processes, namely encoding and therefore are more sensitive measures than recall data for the processes under investigation.

4.2. ERP SME results

Given that we did not replicate a general memory benefit of focus, we should probably rephrase our expectations such that, even in the absence of a group-level behavioural memory effect, we will observe a retroactive SME across all observations because there are cases where contrastive focus accent turns out to be beneficial for memory of alternatives. This is jointly addressed by Hypotheses 2 and 3.

Hypothesis 2 was confirmed with a long-lasting SME that was more positive going for those cases where two alternatives were later remembered than for those cases where only one alternative was later remembered. Observing this modulation in the ERP during encoding implicates that the representation of alternatives is strengthened retroactively when participants process the critical word.

Finally, the interaction with focus accent was significant (in a three-way interaction with laterality). When resolving the interaction, we saw that the retrograde SME at left hemisphere recordings was only obtained for cases with contrastive focus accent, confirming Hypothesis 3.

However, there is a competing explanation for the SME effect: It is also possible that the contrastive focus accent causes deeper encoding of the critical word itself. Therefore, this word will be recalled better during the recall phase. It will then act as a recall cue for the alternatives such that the modulation of the SME for remembering the alternatives will be indirect. In order to address this explanation, we tested whether the critical word was recalled better in the contrastive focus accent condition than in the neutral condition (Hypothesis 4). Hypothesis 4 was not confirmed, replicating the findings from Koch and Spalek (2021). And while we did observe an SME for the critical word itself (confirming Hypothesis 6), this SME was not modulated by the focus condition. Finally, we tested whether recall of the critical word predicted alternative recall (Hypothesis 5). Recall of the critical word was a very strong predictor, confirming Hypothesis 5, which did not interact with the focus condition. However, when we did a single trial analysis with MEMORY FOR THE CRITICAL WORD, MEMORY (for the alternatives) and FOCUS as predictors, thereby controlling for additional variance, we did observe an interaction of MEMORY FOR THE CRITICAL WORD by FOCUS. This is described in more detail below.

Recall of the critical word was also not affected by the strength of the association between a critical word and its alternatives. Therefore, while recall of the critical word plays an important role for alternative recall, it cannot explain the differential effects in the retrograde SME, since recall of the critical word is not modulated by focus accent.

The corresponding EEG results that were obtained in a single trial analysis showed that adding MEMORY FOR THE CRITICAL WORD as a predictor for the mean voltages measured between 300 and 700 ms after the critical word, slightly shifted the observed effects: Now, there is a main effect of MEMORY for alternatives, which does not interact with MEMORY FOR THE CRITICAL WORD, consistent with the conclusion that these two effects are independent. The interaction of MEMORY for the alternatives by FOCUS is replaced by an interaction of MEMORY FOR THE CRITICAL WORD by FOCUS. Splitting the data by MEMORY FOR THE CRITICAL WORD revealed that our critical finding – that is, an interaction between MEMORY for alternatives and FOCUS with a stronger MEMORY for alternatives effect for contrastive focus accent – was restricted to those cases in which the critical word was remembered. This finding has to be taken with a grain of salt since we did not observe a three-way interaction of FOCUS, MEMORY for alternatives and MEMORY FOR THE CRITICAL WORD. This might be the case because the number of observations were unequally distributed, with 1648 observations when the critical word was forgotten and 10,576 when it was remembered.

In the next part of the discussion we will try to make sense of some findings that seem contradictory at first glance: We observed that the memory for the critical word in the recall phase is strongly correlated with successful alternative recall, given the strong memory benefit in the behavioural data (see Table 1). However, this effect is not modulated by the focus accent. The SME for the critical word itself is also not modulated by the focus accent as illustrated in Figure 3. This argues against an account where the focus accent causes deeper encoding of the critical word which is therefore remembered better later on and then serves as a cue for the alternatives. Instead, we observe the following: There is an online retrograde effect of memory for alternatives that is affected by the focus accent such that it is larger when the critical word is contrastively accented. What is puzzling is the observation from the EEG single trial analysis that there is an interaction of MEMORY FOR THE CRITICAL WORD with FOCUS when memory for the critical word is included as a predictor. This seems to suggest that the SME for the critical word is affected by FOCUS, contradicting the findings from the ANOVA, which indicate that the SME for the critical word is not affected by FOCUS. We believe that there are two independent effects during encoding at play: One concerns how well the critical word itself is encoded. The other concerns whether it is encoded as a member of a set of three, that is, the items mentioned in the first sentence of a story. We will come back to this point later and will now discuss how a retrograde memory effect on this set of items can be explained.

4.3. Possible mechanisms

Previous studies that showed a retrograde effect on memory had manipulated arousal (Anderson et al., 2006; Dunsmoor et al., 2015). However, as briefly discussed in the introduction, while contrastive focus accent might increase arousal, memory enhancement for focus alternatives has also been observed for other types of focus marking that are unlikely to modulate arousal: Norberg and Fraundorf (2021) investigated which types of focus marking show the strongest effects on memory for alternatives and concluded that these are contrastive focus accents and the use of *only*. Another type of focus marking, so-called *it*-clefts, improved memory for the focused element itself but not for its alternatives. Thus, it is important to keep in mind that not all types of focus are processed equally. However, contrastive focus accent and *only* seem to cause very similar effects. Gotzner (2019) demonstrated that contrastive focus accent or *only* lead listeners to the same interpretation. In fact, Chierchia (2013) assumes that the contrastive focus accent which we investigated here inserts a silent *only* operator during sentence comprehension. Therefore, an explanation should cover both contrastive focus accent and the presence of *only*, which the arousal explanation does not.

If indicating the relevance of alternatives is not enough to improve memory for these alternatives, what do those cases that lead to a memory improvement have in common? Whenever focus has been attested to improve memory (contrastive focus, focus-sensitive particle *only*), the alternatives are relevant because some form of negation takes place. With contrastive accent, we emphasise that we consider the current utterance to be true for the focused element – but not for its alternatives. This almost automatically leads to a follow-up question: If something is true for the focused element, what then is the case for the alternatives? This may initiate the reinstatement of perceptual and conceptual features of the study context, that is, the alternatives, a process that in turn strengthens the representations of the alternatives and makes them more readily accessible in subsequent memory tests. It has been demonstrated, both in a corpus study (Spalek & Zeldes, 2017) and experimentally in a study in which participants had to produce their own continuations for stories like the ones used in the present study (Gotzner & Spalek, 2022), that alternatives are mentioned significantly more often in continuations after a contrastively accented focus or a focus with *only*.

Braun, Asano and Dehé (2019) used an eyetracking paradigm to investigate the effects of contrastive focus accent and particles on the activation of alternatives. Participants listened to spoken sentences in German and viewed four written words in the quadrants of a computer screen. One of these words was an alternative to the sentence subject. If the subject was realised with a contrastive (L + H*) accent, participants looked more to its alternatives than in a control condition. Somewhat to the authors' surprise, the additive focus-sensitive particle *auch* (also) did not increase looks to the alternatives, even though *auch* presupposes the presence of an alternative. The authors concluded that it is the contrastive accent which makes alternatives salient.

A possible mechanism behind the SME might therefore be increased attention during encoding on the critical word (and its alternatives) in the case of contrastive focus which would make these elements more salient. This might not translate to a memory benefit because activation could spread beyond the three mentioned items (e.g. *pearls*, *rubies*, *sapphires*), activating additional alternatives like, for example, *diamonds* and *emeralds*. In the recall phase, this can then make it more difficult to retrieve the correct items, thereby cancelling a possible memory benefit. Such "confusion effects" have been reported, for example by Gotzner et al. (2016).

The most likely mechanism seems to be the following: Contrastive focus makes participants retrieve previous parts of the story, namely those mentioning the alternatives. Importantly, as already mentioned in the introduction, retrieval has a large effect for later memory tasks. This phenomenon is known as retrieval practice. Retrieval practice is an encoding manipulation by which participants are required to reinstate the episodic context of a prior study episode. Retrieval practice has been consistently shown to improve subsequent memory performance as compared to the mere restudying of the prior episode without retrieval requirements (Karpicke & Roediger, 2008; for a review see Roediger & Karpicke, 2006). In a variety of ERP studies, retrieval practice gave rise to a parietal SME (Bai et al., 2015; Jia et al., 2021; Liu et al., 2017). Supporting the view that the partial SME reflects the retrieval of previously learned information, the effect resembles in its spatio-temporal characteristics the late parietal old/new effect, the ERP correlate of recollection (see Mecklinger & Bader, 2020; Rugg & Curran, 2007, for reviews).

An objection against the retrieval practice account of the retrograde SME could be that even though visual inspection suggests that it displayed a posterior topographic distribution (see Figure 2), this did not hold for the statistical analysis, which implies that the effect was broadly distributed across the scalp. It is conceivable that this broad topographical distribution reflects the co-occurrence of the early and late frontal SMEs and the parietal SME. Component overlap of this kind has typically been reported in SME studies in which the reinstatement/retrieval processes reflected by the parietal SME benefit from the semantic processing revealed by the early frontal SME (Bloom et al., 2018; Kamp et al., 2017) and this could give rise to elaborative processing of the alternatives as reflected by the late frontal SME. Support for this view comes from a recent SME study on schema-based learning, reporting a positive correlation between a frontal (pre-stimulus) SME and a parietal (post-stimulus) SME (Höltje & Mecklinger, 2022), suggesting that successful memory encoding benefits from processes that make semantic information available even before the to-be-encoded event. In sum, we feel safe to conclude that the retrograde SME elicited by the focused element reflects the temporal co-occurrence of both the frontal and parietal SME. Further studies that better allow to disentangle temporally overlapping ERP components are required to disclose the exact component structure of the retrograde SME (see Kamp et al., 2017, for an example).

Let us return to the question why the retrograde SME seems to be restricted to those cases where the critical word is remembered: In most of the theories and experiments presented in the Introduction, the alternative set includes the focused element. In our experiment, this is even inherent in the setup of the stimuli since the critical word is part of a list of three words mentioned in the first sentence. If contrastive focus accent induces listeners to rehearse previous episodes of the story, they will rehearse the alternatives and the critical word, which means that the retrograde effect for alternatives is much more likely to be seen in cases where the critical word has been remembered, too.

Better understanding the mechanisms behind memory for focus alternatives is not easy since the SME is obscured by the fact that the data are affected both by genuine online encoding processes but also by later offline effects, where a remembered critical word can cue an alternative that might otherwise have been forgotten. We believe that we have made a first step towards teasing apart these effects, and we think that the use of event-related potentials is absolutely crucial for understanding the separate contributions of online and offline effects, thereby improving our understanding of the underlying mechanisms.

4.4. Conclusion

To conclude, we observed a retrograde SME that indicates not whether a focused element is or is not remembered but rather how many of its alternatives are remembered. This finding supports the assumption that the memory benefit for alternatives of contrastively focused elements that has been observed in behavioural studies has its origins during the encoding of the focus-marked element and not during the later retrieval phase. In latency and topography, this SME is similar to previously reported SMEs. Given its topography and latency, the retrograde SME observed here presumably reflects successful memory formation for the alternatives supported by retrieval practice, that is, the reinstatement of the perceptual and semantic features of these events, even though alternative interpretations as for example increased attention during encoding cannot unambiguously be excluded. This fits well with several behavioural findings from psycholinguistic experiments showing that contrastive focus makes language users reconsider which alternatives had been mentioned.

Notes

1. A focused element need not be especially marked for focus. For example, if someone had to annotate the position of focus in a written text, this would be where the annotators perceive new, important or contrastive information, even if there is no accent to guide them. Still, it can be confusing to speak of a neutrally marked focused element. In order to avoid confusion, here and in the following, we will use the term "critical word" if we refer to the focused element in both its neutral and its marked form. We thank an anonymous reviewer for this suggestion.
2. Note that hypothesis 4 was not part of the preregistration. Instead, it arose from deliberating some of the comments made by an anonymous reviewer.
3. Note that one of the original authors listed in the preregistration dropped out very early in the project. The project was then joined by two others.
4. "Item" refers to the story (e.g. example 2), "word" to a single word that could or could not be remembered (e.g. "sapphires" in example 2).
5. We also looked at the first half and first quarter of the experiment, but it looks as if the strategies are in place after the first recall phase, that is, from the second block onwards and therefore, adding these additional observations did not increase statistical power.
6. Please note that a main effect of focus could have been due to the comparison of physically different stimuli (with vs. without contrastive focus accent).

Acknowledgements

We would like to thank Beate Bergmann, Felicitas Enders, Yanru Lu and Linda Daniela Steppan for their help with data acquisition and/ or annotating the data and Carsten Schliewe for technical support.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This project has received funding from the European Union's Horizon 2020 research and innovation program (Horizon 2020 Framework Programme) [grant agreement No GAP-677742] awarded to K.S. A.M and R.B. were funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) [Project-ID: 232722074 – SFB 1102, Project A6].

Data availability statement

The raw EEG data, the segments following all preprocessing steps and artifact correction and the annotated recall data can be found here: DOI:10.17605/OSF.IO/VDJ38.

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