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The more you know: Schema-congruency supports associative encoding of novel compound words. Evidence from event-related potentials

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ABSTRACT

We aimed to investigate the neurocognitive mechanisms of event congruency with prior (schema) knowledge for the learning of novel compound words. Event-related potentials (ERPs) were recorded during an incidental learning task, in which novel noun-noun compounds were presented in a semantically congruent context, enabling schema-supported processing, or in a neutral context. As expected, associative memory performance was better for compounds preceded by a congruent context. Although the N400 was attenuated in the congruent condition, subsequent memory effects (SMEs) in the N400 time interval did not differ across conditions, suggesting that the processes reflected in the N400 cannot account for the memory advantage in the congruent condition. However, a parietal SME was obtained for compounds preceded by a congruent context, only, which we interpret as reflecting the schema-supported formation of a conceptual compound representation. A late frontal SME was obtained in both conditions, presumably reflecting the more general inter-item associative encoding of compound constituents.

1. Introduction

Imagine you are reading a newspaper article. Eventually, you stumble over the word *flight shame*. Up to now, you do not know what *flight shame* means, but by reading the article, you learn that it denotes feelings of shame about flying, due to its negative consequences for the environment. This definition provides a plausible explanation for the combination of the words *flight* and *shame* to a novel concept. Now imagine a similar scenario, but this time, you come across the word *acrophobia*. While reading the article, you learn that this phobia is about the fear of heights. This time, it is much harder to track the contribution of each constituent to the novel concept, as you do not know any Greek and thus you cannot make sense of the first constituent. In the first case, you can integrate the novel concept into your prior world knowledge, as you know the underlying concepts. However, this is not possible in the second case, in which you do not understand the contribution of *acro* to the meaning of the word and thus may not integrate this constituent into your prior knowledge structure. An interesting question is how this congruency with prior knowledge influences memory formation of novel compound words, for which a novel concept is created, i.e., the episodic encoding of two previously unrelated items (constituents) into an associative memory representation.

It has long been observed that memory formation is influenced by prior knowledge and schema representations in particular. Memory schemas, which have been originally defined by Bartlett (1932), denote “higher-level knowledge structures that organize lower-level representations from long-term memory” (Gilboa & Marlatte, 2017, p. 618). The schema concept has been used rather loosely in neuroscience and refers to “mental and neurobiological prior associative networks that influence new information processing” (Gilboa & Marlatte, 2017, p. 618). In this framework, an important feature distinguishing a schema from a loose collection or mere co-activation of semantic associations is its structural capacity to combine several prior known concepts to create new ones. Thus, a schema provides a framework that structures the processing of already stored information in relation to not yet acquired information. Schema knowledge does not only influence how information is processed online, but it also impacts which aspects of an event are encoded and retained in memory and which aspects are later forgotten (i.e., Pichert & Anderson, 1977; see Bartlett, 1932; Gilboa & Marlatte, 2017). It is well established that events which are congruent with a given schema are better retained than schema-incongruent events (Alba & Hasher, 1983; Schulman, 1974; Pichert & Anderson, 1977; see Greve et al., 2019, for an overview). The congruency effect has been reported for a wide range of event types and modalities (Atienza et al., 2011; Bein

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et al., 2015; Bein et al., 2014; Greve et al., 2019; Hall & Geis, 1980; Naghavi et al., 2011; Staresina et al., 2009; van Kesteren et al., 2013), although up to now, only few studies have investigated the influence of a memory schema on the learning of associations. Staresina et al. (2009), for example, operationalized event congruency as the plausibility judgment given by participants for the semantic match of a word–color combination. They found superior item memory and also better memory for associated source details (i.e., color information) for congruent events. Bein et al. (2014) presented semantically and associatively related and unrelated word pairs at study and found substantially elevated memory scores for item and associative memory for related (schema supported) words. However, an intriguing question is by means of which processes a schema supports memory formation and retrieval in general and for associations in particular.

On the functional level, the memory advantage for schema-congruent events has been ascribed to easier integration of information that matches representation in semantic memory. This leads to richer and more elaborated memory traces, which are more accessible in a subsequent memory test (Craik & Tulving, 1975; see also Bein et al., 2015). However, it remains to be specified how exactly the presence of a schema supports episodic encoding and leads to beneficial effects on subsequent recognition and recall. Thus, a primary goal of the present study was to assess the mechanisms by which prior semantic schema knowledge facilitates episodic encoding of two unrelated items into an associative memory representation.

An ERP measure that can be used as an index of semantic processing is the N400. During natural reading, the N400 is attenuated for words that are semantically congruent with a preceding context (Kutas & Hillyard, 1980). This is referred to as the N400 effect. Based on a large number of studies, the N400 has been linked to the retrieval and integration of semantic information (see Kutas & Federmeier, 2011, for a review). Of particular interest in the present study was whether the facilitated processing of schema-congruent events is reflected in an attenuation of the N400 (semantic priming effects), and whether this N400 attenuation effect is predictive for subsequent memory of these events.

To explore the mnemonic processes involved in schema-based learning, we used an ERP measure that is indicative of successful memory encoding, the subsequent memory effect (SME), or *D*ifference in neural activity due to *m*emory (*Dm* effect; Paller et al., 1987; Paller & Wagner, 2002). An SME is obtained by comparing ERPs during the encoding of events that are remembered versus forgotten in a subsequent memory test (Sanquist et al., 1980; see Cohen et al., 2015; Paller & Wagner, 2002, for reviews). Thereby, SMEs serve as online measures, reflecting processes that are associated with later successful memory performance. Packard et al. (2017; Exp. 4) applied the SME logic in a schema-based learning study by using a variation of the Deese-Roediger-McDermott (DRM) task (Roediger & McDermott, 1995). In this task, participants were presented with word pairs of category labels and exemplars, the latter being either congruent or incongruent with the category label. In a subsequent memory test, participants were again presented with these exemplars, together with new words and had to decide if the presented word was old (presented in the study phase) or new. Packard et al. (2017) found SMEs for both, semantically congruent and incongruent words. However, these effects unfolded around 200 ms earlier for congruent than incongruent words, which led the authors to conclude that semantic congruency accelerates episodic memory encoding. This interpretation, however, was recently challenged because in the first experiment of their paper, not only congruent words were more often classified as old, but also semantic lures. Consequently, rather than promoting episodic encoding, there might have been a semantic bias, boosting old responses to all exemplars congruent with a studied category. As no semantic lures were present in the experiment in which the SMEs were reported, it cannot be ruled out that the earlier-onsetting SME effect in the congruent condition is an N400 effect, reflecting the facilitated semantic access to items that are semantically related to the target word, rather than the successful episodic encoding of schema-congruent events (Höltje et al., 2019; Tibon et al., 2017).

A recent study from our lab (Höltje et al., 2019) further explored this issue and compared SMEs and memory performance for words which were either congruent ("dog") or incongruent ("sapphire") with a preceding category phrase ("a four-footed animal"). In a surprise subsequent memory test, participants had to discriminate studied (old) words from semantically related lures, i.e., words fitting to a studied category phrase, but not presented during the learning phase ("fox"). Memory was better for congruent words and, in contrast to the results by Packard et al. (2017), Höltje et al. did not find any temporal differences between the SME to congruent and incongruent words. Rather, an SME from 300 to 700 ms with a parietal topographic maximum was obtained for congruent words, only. Notably, this parietal SME can be traced back to successful schema-supported episodic encoding and sheds light on the processes involved in the schema-congruency effect. As similar effects have primarily been found in memory tasks that probe memory for single items (Fabiani et al., 1986), this SME has been linked to the processing of item-specific details, possibly increasing the distinctiveness of an item (Fabiani et al., 1986; Höltje et al., 2019; Karis et al., 1984). In any event, this finding suggests that schemas support memory formation by enhancing the formation of item-specific details, or by integrating new information with pre-existing knowledge. However, our initial question remains: How does schema knowledge facilitate episodic encoding of two unrelated items into an associative memory representation and the creation of a novel concept?

A first hint concerning this question is provided by a recent study by Kamp et al. (2017), in which the learning of associations was investigated in a unitization task. Unitization refers to a condition in which previously separate items are integrated and become represented as a new single unit (Graf & Schacter, 1989). Kamp et al. (2017) presented unrelated word pairs together with a definition, which fosters the processing of those words as compound words with a new joint meaning, i.e., a novel concept (enabling unitization encoding). In a control condition, the two words had to be filled in a sentence, resulting in their processing as separate items. We argue that the definition condition fosters schema-based encoding of the word pair, whereas this form of encoding is largely absent in the sentence condition. Interestingly, Kamp et al. (2017) found a subsequent memory effect with a parietal maximum resembling the SME in the study by Höltje et al. (2019). This effect was present in the definition condition and virtually absent in the control condition. The authors interpreted it as reflecting the encoding of rich item-specific details of the to-be-encoded unit. However, the Kamp et al (2017) study was not designed to investigate contextual support during compound learning. This limits the generalizability of its findings to schema-based learning mainly for two reasons: First, the relationship between the definition and the two words was only established in a non-formalized way, which may have increased the inter-individual variability in the use of this knowledge for the associative encoding of the word pairs. Second, the definition and the sentence condition differ in many more aspects than only the degree of schema-congruency, such as the potential to induce unitized encoding or demands on sentence processing. To overcome these limitations with respect to the current research question, we used an adapted version of the definition-sentence paradigm in which we employed a better operationalization of the semantic relationship between context and compound word, and also established a better control condition (see below).

2. The present study

While the majority of the studies on schema-based learning explored how schema knowledge supports memory for single items or for item-context associations, a primary goal of the present study was to assess the mechanisms by which schema knowledge facilitates episodic encoding of two unrelated items into an associative memory representation. Referring to the example in the introduction, how does superordinate semantic knowledge about what “flying”, and “shame” mean (i.e., the schema) benefit the learning of the novel compound word “flight shame”?

In the present study, participants were presented with novel[1] German compound words, e.g., "Sternensessel" (*star-chair*), which were preceded by either a semantically congruent fictional definition, “Eine Sitzgelegenheit, die man in einem Planetarium findet, heißt” *(A seat that can be found in a planetary is called)* or a neutral definition, “Eine Sitzgelegenheit, die man in einem Büro findet, heißt” *(A seat that can be found in an office is called)*. Their task was to rate how well the compound word is described by the definition. We assumed that the additional semantic relationship between the fictional definition (“planetary”) and the first constituent of the novel compound (“star”), i.e., the modifier constituent, in the congruent condition should facilitate the integration of the compound with the knowledge structure provided by the definition, serving as a schema. The congruent definition provided in the current study meets the requirement of the schema definition to structure already known concepts by explaining how both unrelated concepts can be linked to create a new concept, what might influence information processing and learning of the novel compound words. More precisely, the definition provides a template that explains how prior knowledge, i.e., conceptual knowledge about the compound word constituents, can be used to create a novel concept and how the lexical entries of both word constituents can be linked. This facilitated semantic processing should elevate the activation level of the compound word and by this boost episodic encoding even after a single exposure of the fictional definition. Of note, with this manipulation of schema-congruency, the congruent and the neutral condition only differed in the presence or absence of a semantic relationship between the definition and the modifier constituent of the compound word and all other schema effects were controlled for. As the participants were unaware that a memory test will occur, we could additionally control for the use of intentional encoding strategies that may hinder finding schema-congruency effects on compound learning.

Based on prior literature (e.g., Höltje et al., 2019; Staresina et al., 2009), we expected memory performance in the present study to be better for compound words presented together with congruent than neutral definition contexts. Further, the facilitated semantic processing of congruent compounds should be reflected in an attenuated N400 compared to the neutral condition. If the processes indicated by the N400 effect contribute to memory formation, we expect SMEs with a similar temporal and topographical distribution as the N400 effect (N400-SMEs). These N400 SMEs should be modulated by congruency, with larger subsequent memory effects in the congruent condition, as compared to the neutral condition. Conversely, if the processes contributing to successful memory formation are qualitatively distinct from the aforementioned effects, the SME should either temporally precede or follow the N400 effect with a different topographical distribution. One such component is the parietal SME (see Höltje et al., 2019; Kamp et al., 2017). If similar processes support schema-based episodic encoding of novel word associations, as it is the case for single items, we expect a larger parietally distributed SME for the congruent condition than for the neutral condition. In addition, similar to Kamp et al. (2017), we expect a frontally distributed slow-wave SME for both conditions, reflecting more generally the encoding of associations.

[1] Note that we use novel compound word as an umbrella term denoting compound words that are extremely rare as well as compound words that have never been acquired before, as it can never be completely ruled out that a word combination already occurred. However, we do not assume that these extremely rare compound words are lexicalized and following dual-route approaches of compound word processing, only lexicalized compound words might have a single lexical entry (Libben, 2006). Therefore, we do not assume that the difference between a compound word that is extremely rare or indeed completely new affects our theoretical assumptions.

3. Methods

3.1. Participants

A sample ($N = 43$) of young adults volunteered for this study, having been recruited via flyers and local databases. The required sample size of $N = 20$ was determined with a power analysis (G*Power, Version 3.1.9.4.; Faul et al., 2009) for a one-sided, paired-samples t test on the effect-of-interest, i.e., the SME-difference between high-typical congruent and incongruent trials, based on Höltje et al. (2019), $d_z = 0.59$, $\alpha = 0.05$, $1\text{-}\beta = 0.80$. Data from $n = 13$ participants had to be excluded due to failures during recording ($n = 2$), because the stimulus materials were known from another study ($n = 1$), because they reported that they intentionally studied the stimuli or did not give an indication ($n = 5$) or did not provide enough artifact-free trials ($n = 5$). The final sample consisted of $N = 30$ participants (21 females, with an age range from 18 to 31, $Mdn = 22$ years, $SD = 3.55$). All participants performed above chance in the memory test, which was verified with a binomial test ($p > .05$). All participants were students of Saarland University or volunteers from the community and reported being in good health, not suffering from any neurological or psychiatric conditions and having normal or corrected-to-normal vision. Further, all participants were right-handed, as assessed with the Oldfield Handedness Inventory (Oldfield, 1971), and reported being native speakers of German. Participants gave their informed consent and were reimbursed with 10E/h. Participants were debriefed after the experiment.

The experiment was approved by the ethics committee of the Deutsche Gesellschaft für Sprachwissenschaft (#2017-07-180423) and adhered to the Declarations of Helsinki.

3.2. Stimulus materials

We created 300 novel compound words, adapted from Bader et al. (2014), each consisting of two unrelated nouns. Whenever necessary, the nouns were grammatically modified to create a grammatically-legal and content-wise plausible compound word. Therefore, interfixes (-s, -n, -en) were included and some nouns appear in plural.

For each novel compound word, a congruent and a neutral definition was created, respectively. A definition was stated congruent when it reasonably explains the novel combination of the two nouns to a novel compound word, including a new concept. This was achieved by using a systematic pattern of relationships between compound head, compound modifier and particular words of the definition sentence as construction principles.[2]

Eine Sitzgelegenheit, die man in einem Planetarium findet, heißt…
Sternensessel (congruent)

(A seat that can be found in a planetary is called… star-chair)

Eine Sitzgelegenheit, die man in einem Büro findet, heißt…
Sternensessel (neutral)

(A seat that can be found in an office is called… star-chair)

Ein Lexikon, das Gärtner benutzen, heißt…
Gemüsebibel (congruent)

(A dictionary used by gardeners is called… vegetable-bible)

Ein Lexikon, das Lehrer benutzen, heißt…
Gemüsebibel (neutral)

[2] Note that the compound words were endocentric and subordinate in that the first word was always the modifier, and the second word was always the head.

(A dictionary used by teachers is called… vegetable-bible)

Firstly, the main component of the definitions was a noun phrase, including a single noun (the *base noun*; "seat") and a relative clause ("that can be found in a planetary"). The base noun bore a semantic relationship to the head of the novel compound word ("chair") and thus established a link to the core concept. Secondly, the relative clause further specified the established concept. Congruent and neutral definitions only differed in one single noun in the relative clause, i.e., the *critical noun* ("planetary" in the congruent definition, and "office" in the neutral definition). In the congruent definition, the critical noun ("planetary") bore a semantic relationship to the modifier of the novel compound word ("star"). Thus, the congruent definition combined the underlying concepts of modifier and head to a coherent concept. In the case of the neutral definition, the critical noun ("office") was semantically unrelated to the modifier of the novel compound word ("star"). Consequently, in the neutral condition, the underlying concepts of modifier and head were not combined to a coherent concept.

Definitions always contained 5–12 words and were completed by two German versions of the formulation "is called", in order to establish a more natural processing situation. Those were used in a way that did not require grammatical alternations of the sentences. For both sets, each formulation occurred in approximately half of the trials. The three dots following the definition in the example are for illustrative purposes, only, and were not shown in the experiment.

For the memory test, we additionally created 150 recombined compound words, as well as 118 new compound words. New compound words consisted of two unrelated nouns, which were not used elsewhere in the material (e.g., Ankermönch *anchor-monk*, Damenraster *lady-grid*). Recombined compound words were included to assure that participants would not be able to solve the task by using item recognition alone and constructed by newly combining the modifier and the head of two different compound words. It was assured that the nouns still were semantically unrelated and for each such pair of compound words, only one of two possible recombined compound words was used, to avoid the repetition of the constituents in different recombined word pairs. For example, we recombined the word Sternensessel (*star-chair*) with the word Magnetenozean (*magnet-ocean*) to Magnetensessel (*magnet-chair*) and omitted Sternenozean (*star-ocean*) from the test list. The two compounds used for recombination were always of the same grammatical gender and contained the same type of interfix, if any.

To select the final stimulus material for the EEG study, two rating studies with independent samples of participants were conducted using E Prime 2.0 (Psychology Software Tools, Pittsburgh, PA). In these studies, we explored the above-described pattern of semantic relationships between the nouns on the one hand and the explanative value of the congruent and neutral definitions to the compound word on the other hand. The semantic relationship within each noun word pair was evaluated by $n = 12$ participants on a four-point scale (1 = *not at all*, 2 = *rather not*, 3 = *rather*, 4 = *absolutely*) according to how well the two words are related concerning their meaning. Hereby, relatedness was described rather broadly, including relatedness due to describing the same concept, shared features of the underlying concepts (categorical relationship) or frequent co-occurrence (thematic relationships). Participants had 5 s to respond do each word pair. The explanative value of each definition, i.e., how well the combination of the two words in the novel compound word denotes the concept given by the definition, was rated on an identical four-point scale by $n = 16$ participants. Response time was restricted to 10 s per trial. None of the participants from these rating studies participated in the main experiment. We selected 240 compound words, together with their recombined word pair, and 80 new compound words for the final stimulus materials. The congruent definition was rated as significantly more explaining the novel compound word than the neutral definition ($M_{\text{congruent}} = 3.16$, $SD = 0.40$, $M_{\text{neutral}} = 1.69$, $SD = 0.36$, $t(239) = 42.99$, $p < .001$, $g_{av} = 3.76$)[3].

Compound words had a length ranging from 7 to 18 letters ($M = 11.98$, $SD = 2.09$), for to-be-learned compound words, ranging from 7 to 16 letters ($M = 11.93$, $SD = 2.03$) for recombined compound words, and ranging from 7 to 18 letters for new compound words ($M = 12.37$, $SD = 2.58$). The normalized lemma frequency for the constituents ranged from 0.02 to 264.38 occurrences per million[4] for compound words and recombined compound words and from 0.11 to 394.69 for new compound words. Compound constituents were rated as being semantically unrelated ($M = 1.30$, $SD = 0.23$, for compound words, $M = 1.28$, $SD = 0.22$, for recombined compound words and $M = 1.30$, $SD = 0.14$, for new compound words)[5]. Stimulus materials are available upon request from the first author.

The selected stimuli were divided into two sets (Set 1 and Set 2), consisting of 120 compound words each. Two encoding lists were created, whereby for the first list, compound words of Set 1 were presented with a congruent context and compound words of Set 2 were presented with a neutral context. This assignment was reversed for the second list. Which encoding list was used varied across participants, whereby both lists were presented approximately equally often.

To create lists for the test phase, stimuli were further divided into four subsets of 60 compound words, each, by halving Set 1 and Set 2, respectively. This enabled us to counterbalance the type of presentation of a learned compound word in the test phase, i.e., either as intact or recombined compound word. Consequently, compounds of each subset were presented once as intact and once as recombined across test lists, so that when compound words of Set 1a and Set 2a were presented as intact compound words, the other half (Set 1b and Set 2b) was presented as recombined compound words, and vice versa. Thus, for each encoding list, the same 2 test lists were created, resulting in 4 possible combinations of encoding and test lists. Each test list consisted of 120 intact compound words, 60 recombined compound words, and 80 new (yet unpresented) compound words. The new compound words were identical for each participant. Across all sets (1 and 2) and subsets (1a, 1b, 2a, 2b), there were no statistically reliable differences in normalized lemma frequency of compound constituents, compound word length or semantical relationship between compound word constituents. Further, there were no significant differences in context fit between Set 1 and Set 2 in the encoding lists.

Stimulus presentation in the experiment was pseudo-randomized for the encoding and test phase, with the limitation of not more than 3 consecutive trials in the same context condition (encoding phase) or not more than 3 consecutive trials requiring the same response (test phase).

3.3. Procedure

After having given their written–informed consent, participants completed several questionnaires, one about their general health, one about demographic aspects and the Oldfield Handedness Inventory (Oldfield, 1971). Next, EEG was applied, and participants were sat in a dimly lighted, sound-absorbing chamber.

The experiment was created using E Prime 2.0 (Psychology Software Tools, Pittsburgh, PA) and presented on a 19-in. monitor with a

[3] Note that due to the time restriction, there were missing values in rating responses. However, a minimum of 11 ratings were available for each version (congruent and neutral) of the definition.

[4] Lemma frequency was estimated from dlexDB (Heister et al., 2011). For one noun, there was no respective entry.

[5] Similar to the rating study on definition fit, there were missing values in the ratings on semantical relatedness. However, a minimum of 11 ratings were available for each word pair.

resolution of 1280 × 1024 px. The experiment proper consisted of an incidental encoding phase, a retention interval with a duration of 10 min and a test phase (see Fig. 1 for an overview of trial procedures). All stimuli of encoding and test phase were presented in white font against a black background.

During the encoding phase, participants were presented with 240 definitions, half of them congruent and half of them neutral, followed by the respective novel compound word. Participants were instructed to rate on a scale from 1 (*not at all*) to 4 (*absolutely*) how well the novel compound word denotes the concept given by the definition. A trial started with a fixation cross, with a duration of 500 ms. Then, the definition was presented stepwise. The noun phrase was presented for 1000 ms, followed by the presentation of the relative clause and the words "is called" for additional 3500 ms. After another fixation cross with a continuously jittered duration from 950 to 1050 ms, the compound word was presented in the center of the screen for 2000 ms. A 500 ms blank screen followed the compound word. Then the answer screen appeared for up to 3 s but was terminated as soon as the participants gave their response. Their task was to rate how well the compound word is described by the preceding definition, providing a measure of the semantic congruency between the definition and the compound word. The answer screen contained the question of how well the compound word is described, as well as the labels for the response scale. Participants responded on a keyboard by using the keys ×, c, n, and m with their index and middle fingers of each hand. The scale was ascending for a part of the participants and descending for the other part of participants. A 500 ms blank followed until the next trial started. Before the encoding phase, participants completed 8 practice trials to familiarize with the task.

The encoding phase was followed by a 10-minute retention interval. During this interval, participants performed two distractor tasks. At first, an adapted computerized version of the Digit Symbol Task (Wechsler, 1955) from Häuser et al. (2019) was performed for approximately 5 min, followed by 2.5 min of backwards counting in steps of 3. Only then, participants were told about the upcoming test phase.

During the test phase, participants were presented with one of the two test list versions, consisting of 120 intact compound words, 60 recombined compound words and 80 new, i.e., yet unpresented compound words. A trial started with a continuously jittered fixation cross (950–1050 ms). Then, the compound word was presented (for up to 3000 ms), until participants gave their response. Participants gave their answer on a keyboard by using the keys f, j and k to indicate if the compound word was intact, recombined or new. Key assignment was varied by using a latin-square design, ensuring that across participants, each response option was used with an approximately equal frequency. After a 500 ms blank screen, participants were asked to indicate their confidence on the previous response (*sure* or *unsure*) using their index fingers, whereby key assignment was ascending for a part of the participants and descending for the other part of participants. The confidence scale remained on the screen for up to 3000 ms or until participants gave their response and was only presented if a response had been logged on the compound word. A trial ended with a blank screen, which was presented for 500 ms.

In both, learning and test phase, there were self-paced breaks after 60 trials (encoding phase) or 65 trials (test phase), respectively.

3.4. Data acquisition and pre-processing

The EEG was continuously recorded from 28 Ag/AgCl scalp electrodes (Fp1/2, F7/8, F3/4, Fz, FC5/6, FC3/4, FCz, T7/8, C3/4, Cz, CP3/4, CPz, P7/8, P3/4, Pz, O1/2, A2) using BrainVision Recorder 1.0 (Brain Products, Gilching, Germany), whereby all electrodes except from A2 were embedded in an elastic cap (Easycap, Hersching, Germany). Electrode positions followed the extended international 10–20 system (Jasper, 1958). AFz was chosen as ground electrode and two electrodes were applied on the left (A1) and right (A2) mastoid, respectively. Electroocular activity was assessed via four additional electrodes, which were placed above and below the right eye and outside the outer canthi

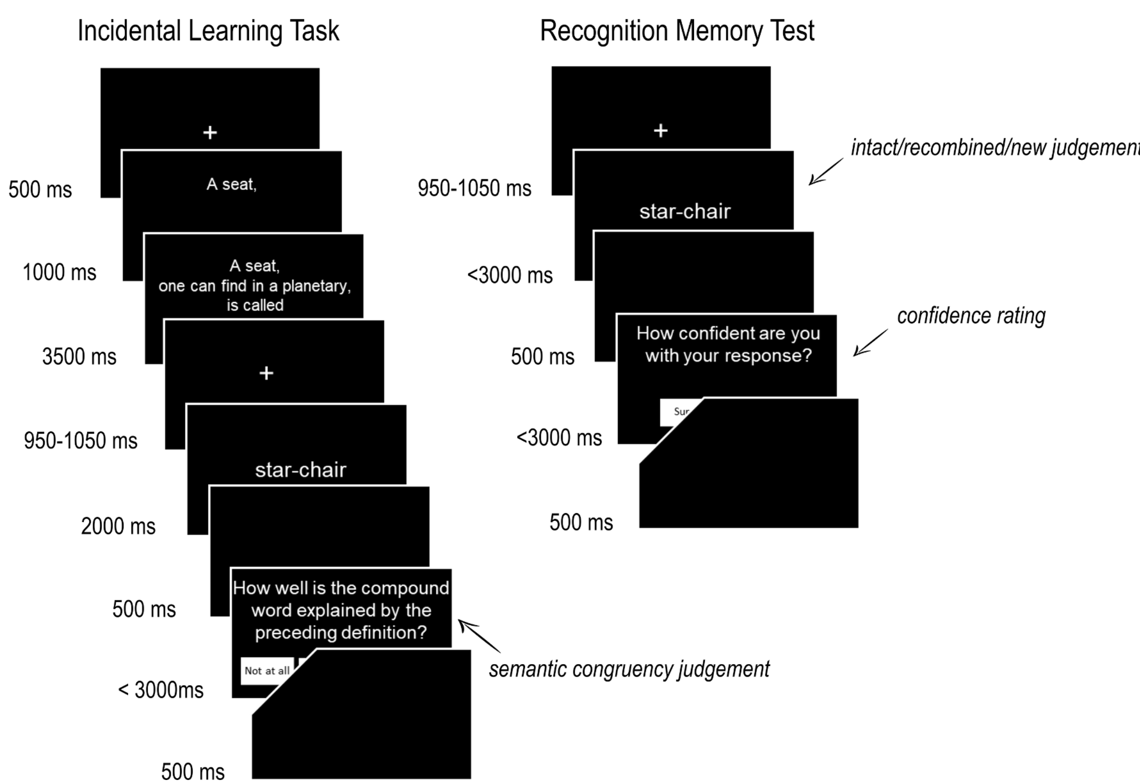

Fig. 1. Illustration of the trial procedures in the incidental learning task (left) and in the recognition memory test (right). Note that the depicted example stimuli are English translations of the original German stimulus materials.

of both eyes. The signal was online referenced to the left mastoid electrode (A1) with the exception of one participant for whom some eye and mastoid electrode channels were interchanged by mistake. For this dataset, data were online referenced to the left canthus electrode. Channel assignment was corrected offline and in an additional step, data were re-referenced to left mastoid. Thus, before the actual pre-processing, all datasets had the same reference. All electrode impedances were kept below 5 kOhm with the exception of the electroocular electrodes' impedances. Data were sampled at 500 Hz. An online filter from 0.016 Hz (time constant 10 s) to 250 Hz was applied.

Offline, the data were pre-processed using the EEGLAB (version 2019.1; Delorme & Makeig, 2004) and ERPLAB (version 7.0; Lopez-Calderon & Luck, 2014) toolboxes for MATLAB (MathWorks, Inc.). Therefore, the data from the encoding phase were sampled down to 250 Hz and re-referenced to the average of left and right mastoid. Thereafter, data were filtered for the ICA, using a second-order Butterworth bandpass-filter from 0.5 Hz to 30 Hz (-6dB half-amplitude cutoff, with DC removal). 50 Hz powerline fluctuations were removed with a Parks-McClellan notch filter (default setting order 180; with DC removal; see Parks & McClellan, 1972 for the original algorithm). Data were pre-segmented by discarding all data points exceeding a time period from 1000 ms before a stimulus onset marker to 2500 ms after a stimulus onset marker. Then, bad segments and experimental breaks, as well as practice trials, were manually discarded.

The independent component analysis (ICA) infomax algorithm *runica* was used to later identify and correct for ocular and muscular artifacts. The resulting IC weights and sphere matrix were then applied to the original data, that were first preprocessed as follows: Data were sampled down to 250 Hz and re-referenced to the average of left and right mastoid. Thereafter, data were filtered with a second-order Butterworth bandpass-filter from 0.05 Hz to 30 Hz (-6dB half-amplitude cutoff, with DC removal). 50 Hz powerline fluctuations were again removed with the Parks-McClellan notch filter. Thereafter, data were presegmented identical to as before the ICA (1000 ms before to 2500 ms after a stimulus onset marker with manual removal of the same bad segments, breaks and practice trials). After, the ICA weights and sphere matrix were applied, and components associated with eye movements and muscular artifacts were identified and removed (up to 5 components per participant).

Data were then segmented into epochs of 1996 ms around compound word onset, including a 200 ms baseline. Following baseline correction, a semi-automatic artifact rejection was applied, using the following criteria: a maximally allowed amplitude of −75 up to 75 μV, a maximal difference of values of 100 μV during intervals of 200 ms (window steps of 100 ms), a maximally allowed voltage step of 50 μV/s and a maximum of 200 ms of sample points with a deviation from −0.5 to 0.5 μV from the maximum voltage in this epoch.

To calculate average N400 effects, $M = 110.6$ trials (*SD* 15.53, *range* 56–120) were used in the congruent condition and $M = 110.7$ trials (*SD* 15.63, *range* 60–120) were used in the neutral condition. For the SME analyses, only trials from intact compound words were included and compounds which were used in recombined pairs during the test phase had to be discarded. Hence, average ERPs for the SME analyses were calculated for subsequent hits (intact compound words identified as intact) and subsequent misses (intact compound words identified as recombined or new) for each condition (congruent and neutral context), respectively. Due to an insufficient number of trials per level, the collected confidence ratings were not considered. ERPs of subsequent hits were based on $M = 36.33$ trials (*SD* 9.06, *range* 14–50) in the congruent condition and on $M = 26.5$ trials (*SD* 7.83, *range* 8–41) in the neutral condition. For ERPs of subsequent misses, $M = 17.4$ trials (*SD* 6.96, *range* 8–38) were used in the congruent condition and $M = 27.3$ trials (*SD* 6.66, *range* 11–42) were used in the neutral condition.

A common phenomenon in studies using SMEs are differential trial numbers for subsequently remembered and forgotten information (e.g., Höltje et al., 2019; Kamp, 2020; Otten & Donchin, 2000) that arise naturally when memory performance is above chance. The differential trial number across conditions results in a worse signal-to-noise ratio for the condition with fewer trials, i.e., the misses, as compared to hits, decreasing statistical power. However, based on a simulation study (Gibney et al., 2020), we assume that our minimal trial criterion is adequate, and we do not face a power issue, given our relatively large sample and the fact that our effects-of-interest, i.e., subsequent memory effects, are rather large effects (e.g., for the parietal SME approx. 2 μV in Kamp et al., 2017, estimated from Fig. 3A and 1.8 μV for congruent exemplars in Höltje et al., 2019).

3.5. Data analysis

For all analyses, the significance criterion of $p < .05$ was applied. Data were analyzed using R (version 3.6.1; R Core Team, 2019) and RStudio (Version 1.2.5001; RStudio Team, 2019) and IBM SPSS statistics (version 26). Whenever non-hypothesis-driven multiple testing was required, the Bonferroni-Holm correction (Holm, 1979) was applied. The reported corrected *p*-values were calculated with the function *p. adjust* of the R package *stats* (R Core Team, 2019).

To capture associative memory performance by considering intact and recombined compound words irrespective of correct rejections of new compound words, an associative *Pr* (hits - false alarms) was calculated. Therefore, the associative hit rate was calculated as the amount of compound words, correctly identified as intact, divided by the sum of all intact trials, classified as either intact or recombined. The associative false alarm rate was calculated as the sum of all recombined items classified as intact, divided by the number of recombined items either classified as recombined or intact. Behavioral outliers were defined as extreme values, i.e., with a standardized *z*-value greater than 3.29 above the mean (Field, 2009, p. 179). No data had to be excluded from behavioral analyses.

To analyze ERP data, we pursued a two-step strategy. In a first step (manipulation check), we aimed to evaluate the congruency manipulation. Therefore, we examined N400 congruency effects by comparing ERPs for congruent and neutral trials. As subsequent memory was not relevant for this analysis, all artifact-free trials of the learning phase (subsequently presented as intact or recombined) were used in this analysis. In a second step, our goals were to examine (i) whether the N400 effect was modulated by subsequent memory and (ii) whether we find similar early parietal and late frontal subsequent memory effects as in prior studies (Höltje et al., 2019; Kamp et al., 2017). As subsequent memory effects are difficult to interpret for recombined compound words, due to the different study contexts of the two constituents, only intact trials were used in these subsequent memory analyses.

As in previous studies, we used a central-parietal electrode cluster to examine N400 effects (Brothers et al., 2020; Kuperberg et al., 2020), whereby we chose near spatial neighbors in case our electrode montage did not cover the respective positions. The electrode cluster included electrodes Cz, CPz, C3/4. To avoid spatial overlap between the N400-SME and the parietal SME, CP3/4-electrodes were omitted from the N400 cluster. For N400 related analyses, we selected an a-priori time window from 300 to 500 ms (e.g., Höltje et al., 2019; Stites et al., 2016). However, due to the slightly delayed N200 preceding the N400, we adjusted this time window post-hoc to 350–500 ms, to obtain a valid measure of the N400 effect (see Yagoubi et al., 2008, for similar adjustments). Interestingly, in the neutral condition, the N400 effect seems to extend until approximately 700 ms, whereby it is attenuated in the congruent condition (Fig. 2). Critically, the topographical distribution of this extended N400 effect resembles the distribution of an N400 effect in a remarkable way. Therefore, we analyzed the extended N400 effect in an additional, post-hoc selected time window from 500 to 700 ms (post-N400 time window).

The same electrode cluster and time windows were used to test

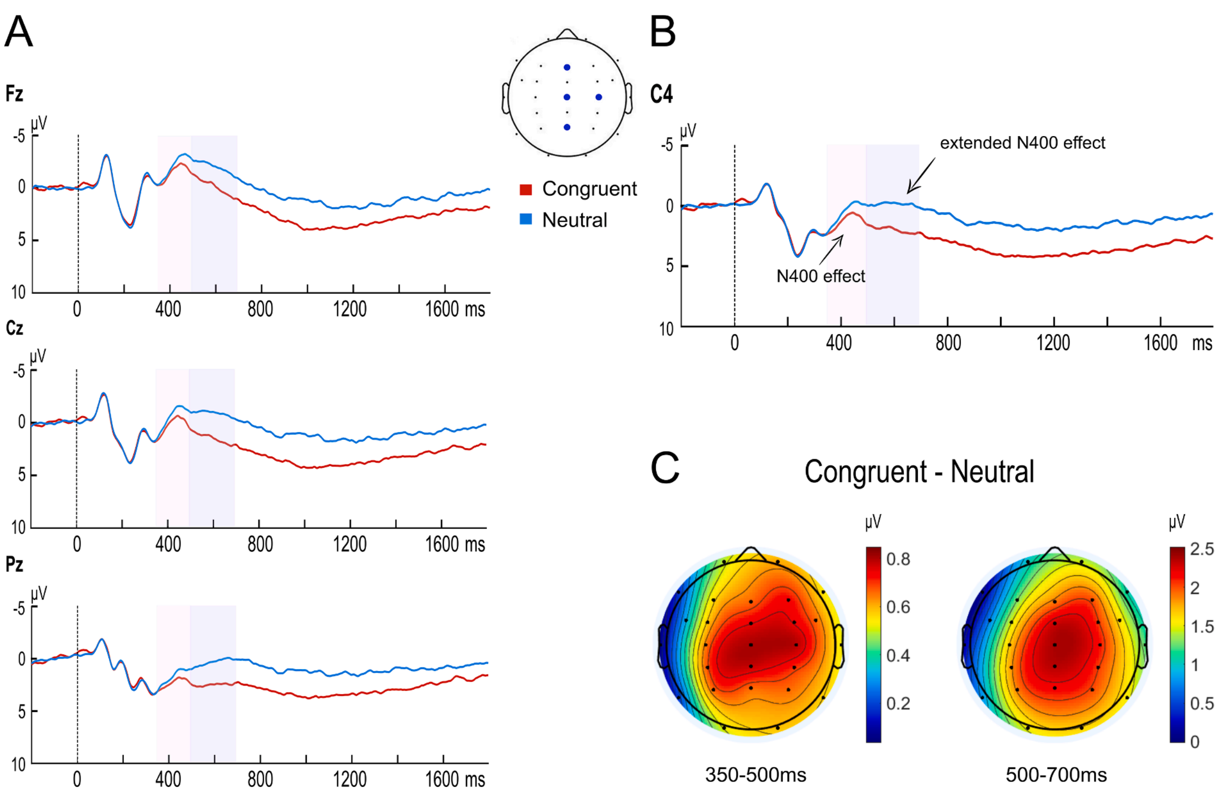

Fig. 2. N400 Effects. Panel A depicts ERP waveforms of the encoding phase for compound words presented in a congruent and in a neutral context. Panel B depicts N400 effects at electrode C4, where the N400 and the extended N400 effect can be observed particularly well. Panel C depicts the topography of the N400 effect (congruent - neutral) in both time windows.

whether N400 effects were modulated by subsequent memory (N400-SME). Electrodes for the parietal and frontal SME electrode clusters were selected on the basis of Kamp (2020), whereby we again chose near spatial neighbors in case our electrode montage did not cover the respective positions. The parietal SME cluster included electrodes CP3/4, P7/8, P3/4, Pz, O1/2. Consistent with prior research on the parietal SME and the N400 (Höltje et al., 2019; Packard et al., 2017), the same time window as for the a priori defined N400 and the post-N400 time window were chosen for the analyses of the parietal SME. However, similar to the N400 effect, visual inspection revealed that the maximum of the parietal SME was shifted in time to 700 – 900 ms. The temporal shifts of the N400 and SME effects were presumably caused by the more multifaceted congruency manipulation, requiring prolonged semantic processing, as compared to the Höltje et al. (2019) study in which merely short category cues were used as context manipulations. Therefore, we additionally analyzed the parietal SME in the post-hoc defined time window from 700 to 900 ms. The frontal SME was analyzed on a frontal-central cluster, including electrodes Fp1/2, F7/8, F3/4, Fz, FC5/6, FC3/4, FCz, in a time window from 900 to 1200 ms (Höltje et al., 2019). Note that we re-ran the analyses for a time window from 1200 to 1796 ms, similar to Kamp et al. (2017), yielding qualitatively identical results, which are not reported here. All topographical profile analyses were conducted with the electrodes F3, Fz, F4, C3, Cz, C4, P3, Pz and P4.

As sphericity is usually violated in EEG data, we used the multivariate approach of repeated measure analysis of variance (MANOVA), which is more robust against such violations of sphericity (Dien & Santuzzi, 2005; Picton et al., 2000).

For the sake of readability, we only report significant effects including the factors congruency or memory. Significant effects are further explored in follow-up MANOVAs and paired-samples *t* tests. As measures of effect size, we report Hedges' g_{av} for effects from paired-samples *t* tests with the formula provided in the spreadsheet (Version 5; Lakens, 2013) and Pillai's trace, which is identical to partial eta-squared (η^2), for multivariate analyses of variance (MANOVAs), respectively.

4. Results

4.1. Behavioral results for the encoding phase

We compared the responses for the rating during the encoding phase between the congruent and the neutral condition with a paired-samples *t* test. As expected, participants rated compound words in the congruent condition as being explained better than compound words in the neutral condition, $t(29) = 24.10$, $p < .001$, $g_{av} = 4.82$ ($M_{congruent} = 3.20$, $SD = 0.34$; $M_{neutral} = 1.68$, $SD = 0.26$).

4.2. Behavioral results for the test phase

To test if and how congruency modulates memory performance, we calculated a Congruency (congruent, neutral) × Type (hit, false alarm) - MANOVA. This analysis revealed a main effect of congruency, $Pillai = 0.57$, $F(1, 29) = 38.67$, $p < .001$, a main effect of type, $Pillai = 0.86$, $F(1, 29) = 173.94$, $p < .001$, and a significant interaction, $Pillai = 0.28$, $F(1, 29) = 11.16$, $p = .002$. Further examination revealed that only hit rates differed significantly across congruency conditions, $t(29) = 10.64$, $p < .001$, $g_{av} = 1.22$ (one-sided, $M_{congruent} = 0.76$, $SD = 0.12$, $M_{neutral} = 0.60$, $SD = 0.13$), whereas no such differences were found for false alarm rates, $t(29) = 1.50$, $p = .144$, $g_{av} = 0.24$ (two-sided, $M_{congruent} = 0.36$, $SD = 0.19$, $M_{neutral} = 0.31$, $SD = 0.16$). Consequently, associative memory performance, indicated by association-based *Pr*, was higher in the congruent than in the neutral condition, $t(29) = 3.34$, $p = .001$, $g_{av} = 0.64$ (one-sided, $M_{congruent} = 0.40$, $SD = 0.19$, $M_{neutral} = 0.29$, $SD = 0.15$).

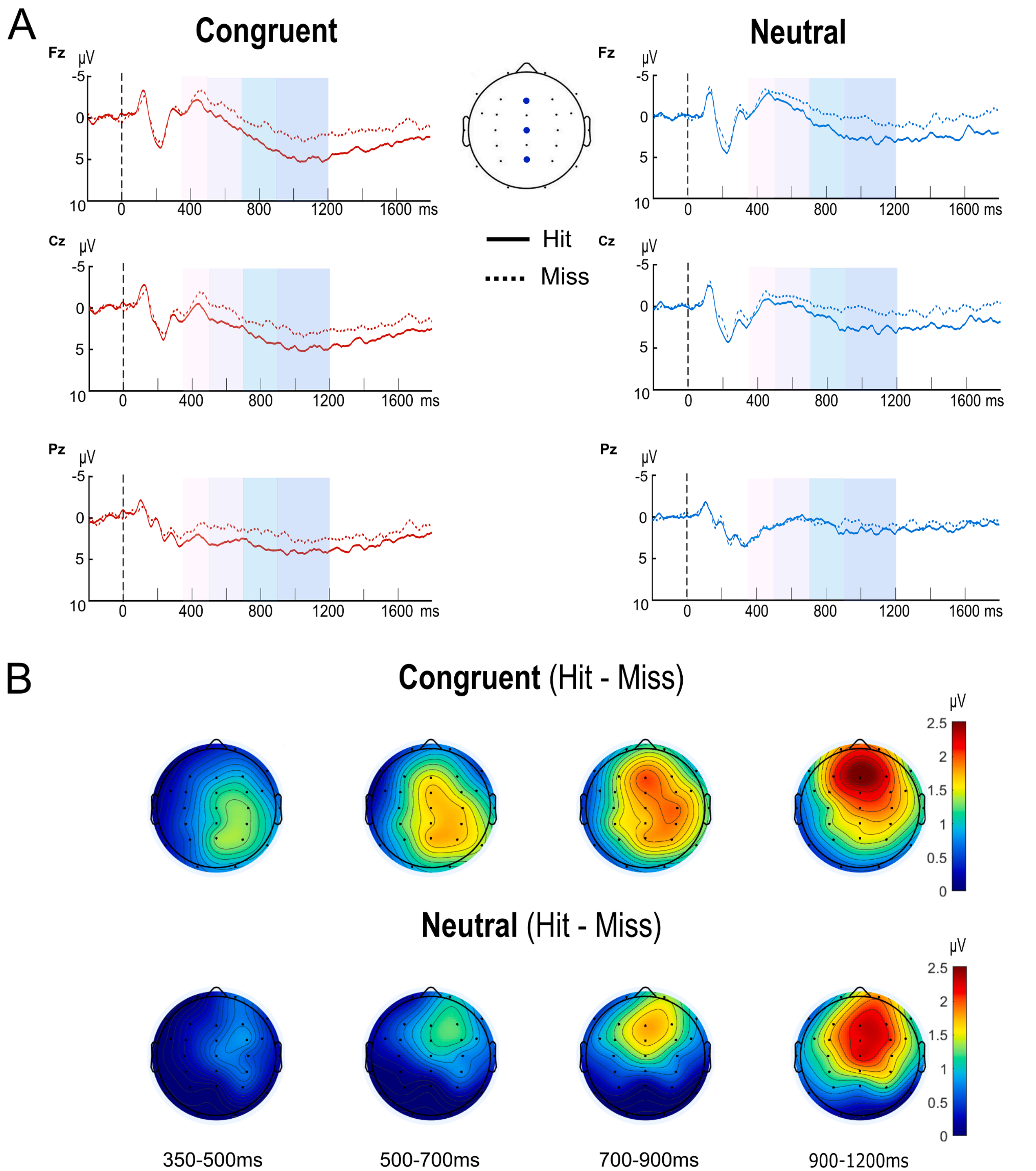

Fig. 3. Subsequent Memory Effects. Panel A depicts subsequent memory effects in the congruent and in the neutral condition. The topographic maps of the subsequent memory effect (hit - misses) in all four analyzed time windows are illustrated in Panel B, for each condition, separately.

4.3. ERP results

Fig. 2 depicts the grand average ERP waveforms elicited by the compound words in the encoding phase. Effects of congruency for the N400 start to emerge at approximately 350 ms with a right-central topography. The N400 is attenuated in the congruent condition relative to the neutral condition. Interestingly, in the neutral condition, the N400 effect appears to be extended until approximately 700 ms, whereby it is attenuated in the congruent condition. The subsequent positivity seems to start earlier in the congruent condition. The subsequent memory effects in both conditions are illustrated in Fig. 3. Subsequently remembered compound words show more positive ERP deflections than subsequently forgotten ones. In the congruent context condition, ERPs to subsequent hits and misses start to diverge at approximately 300 ms at parietal sites, with maximal effects occurring between 500 and 900 ms post-stimulus. In addition, there is a late SME, which is present at frontal recording sites in both conditions. The late frontal effect appears to be largest in a time window between 900 and

Type of effect	350-500ms	500-700ms	700-900ms	900-1200ms
Congruency (All trials)	**A-priori: N400 effect** Less negative amplitudes in congruent vs. neutral context	**Post-hoc: N400 effect** Less negative amplitudes in congruent vs. neutral context		
Subsequent memory and congruency (Subsequently intact trials)	**A-priori: N400-SME** More positive amplitudes for subsequently remembered vs. forgotten compound words, no congruency modulation of effect	**Post-hoc: N400-SME** More positive amplitudes for subsequently remembered vs. forgotten compound words, no congruency modulation of effect	**Post-hoc: parietal SME** More positive amplitudes for subsequently remembered vs. forgotten compound words in congruent condition	**A-priori: frontal SME** More positive amplitudes for subsequently remembered vs. forgotten compound words, no congruency modulation of effect
	A-priori: parietal SME More positive amplitudes for subsequently remembered vs. forgotten compound words in congruent condition			

Fig. 4. Overview of the ERP analysis strategy and the results of the statistical analyses.

1200 ms but continues until the end of the segment. These observations were examined in a series of statistical analyses, whereby we first present a-priori defined analyses, followed by post-hoc analyses (see Fig. 4 for an overview of the analysis approach).

4.3.1. *N400 congruency and subsequent memory effects (350–500 ms)*

A paired-samples *t* test on the central-parietal N400-cluster in the a-priori defined time window from 350 to 500 ms was conducted to compare mean amplitudes in the congruent and in the neutral condition. Consistent with our hypotheses, mean amplitudes were more positive in the congruent condition, as compared to the neutral condition, $t(29) = 3.21$, $p = .002$ (one-sided), $g_{av} = 0.20$ (see Fig. 2).

In a next analysis step, we aimed to investigate whether the N400 contributes to successful memory formation. Therefore, a Memory × Congruency-MANOVA was calculated in the a-priori defined N400 time window from 350 to 500 ms on the central-parietal N400 electrode cluster. This analysis only revealed a significant main effect of memory, *Pillai* = 0.18, $F(1, 29) = 6.18$, $p = .019$, with in general more positive amplitudes for remembered, as compared to forgotten compound words, irrespective of congruency. Thus, we observed the predicted N400 effect with less negative amplitudes in the congruent, as compared to the neutral condition, but the N400-SME was not modulated by congruency (Fig. 5).

4.3.2. *Parietal subsequent memory effects in the N400 (350–500 ms) and post-N400 (500–700 ms) time windows*

A Memory × Congruency × Time Window-MANOVA on the parietal electrode cluster revealed a significant main effect of time window, *Pillai* = 0.26, $F(1, 29) = 10.00$, $p = .004$, a significant main effect of congruency, *Pillai* = 0.23, $F(1, 29) = 8.66$, $p = .006$, a significant main effect of memory, *Pillai* = 0.22, $F(1, 29) = 8.18$, $p = .008$, as well as a significant interaction of time window and congruency, *Pillai* = 0.44, $F(1, 29) = 22.96$, $p < .001$, and a significant interaction of congruency and memory, *Pillai* = 0.13, $F(1, 29) = 4.35$, $p = .046$. To resolve the significant interaction of time window and congruency, data were averaged over the factor memory to calculate Bonferroni-Holm-corrected, follow-up paired-samples *t* tests on congruency for each time window, separately. Those revealed more positive amplitudes in the congruent than in the neutral condition in the later time window, $t(29) = 4.05$, $p < .001$, $g_{av} = 0.48$, but not in the earlier time window, $t(29) = 0.25$, $p = .807$, $g_{av} = 0.02$. To resolve the significant interaction of congruency and memory, data from both time windows were averaged and follow-up paired-samples *t* tests on memory were calculated for the congruent and the neutral condition, separately. Hereby, a significant parietal subsequent memory effect with more positive amplitudes for remembered, as compared to forgotten trials was found in the congruent condition, $t(29) = 3.23$, $p = 0.002$ (one-sided), $g_{av} = 0.37$, but not in the neutral condition, $t(29) = 0.25$, $p = .808$ (two-sided), $g_{av} = 0.03$ (see Fig. 5). Thus, consistent with our hypotheses, we found a parietal SME that was modulated by congruency being only statistically reliable in the congruent condition.

4.3.3. *Frontal subsequent memory effects (900–1200 ms).*

A Memory × Congruency-MANOVA on frontal electrodes revealed a significant main effect of congruency, *Pillai* = 0.28, $F(1, 29) = 11.29$, $p = .002$, with more positive amplitudes in the congruent, as compared to the neutral condition, and a significant main effect of memory, *Pillai* = 0.49, $F(1, 29) = 27.58$, $p < .001$, with more positive amplitudes for remembered than for forgotten trials. Consequently, consistent with our hypotheses, we found a late frontal SME that is independent of congruency (see Fig. 5).

4.3.4. *Post-hoc analyses of the extended N400 effect (post-N400 time interval)*

An additional paired-samples *t* test on the central-parietal N400-cluster was conducted in the post-N400 time window (from 500 to 700 ms), using the same central-parietal electrode cluster. Again, mean amplitudes were more positive in the congruent condition, as compared to the neutral condition, $t(29) = 6.31$, $p < .001$ (two-sided), $g_{av} = 0.54$ (see Fig. 2). To explore whether this effect was modulated by subsequent memory, we calculated a Memory × Congruency-MANOVA. As in the N400 time interval, this analysis revealed a significant main effect of congruency, *Pillai* = 0.27, $F(1, 29) = 10.52$, $p = .003$, as well as a significant main effect of memory, *Pillai* = 0.32, $F(1, 29) = 13.70$, $p = .001$ (see Fig. 5). Thus, as in the N400 time interval, we found congruency effects and subsequent memory effect also in the post-N400 time window, with no interaction between the two factors.

4.3.5. *Post-hoc analyses of the late parietal subsequent memory effect*

An additional post-hoc analysis on the parietal cluster in the time window from 700 to 900 ms was computed. A Memory × Congruency-MANOVA on the parietal electrode cluster revealed a significant main

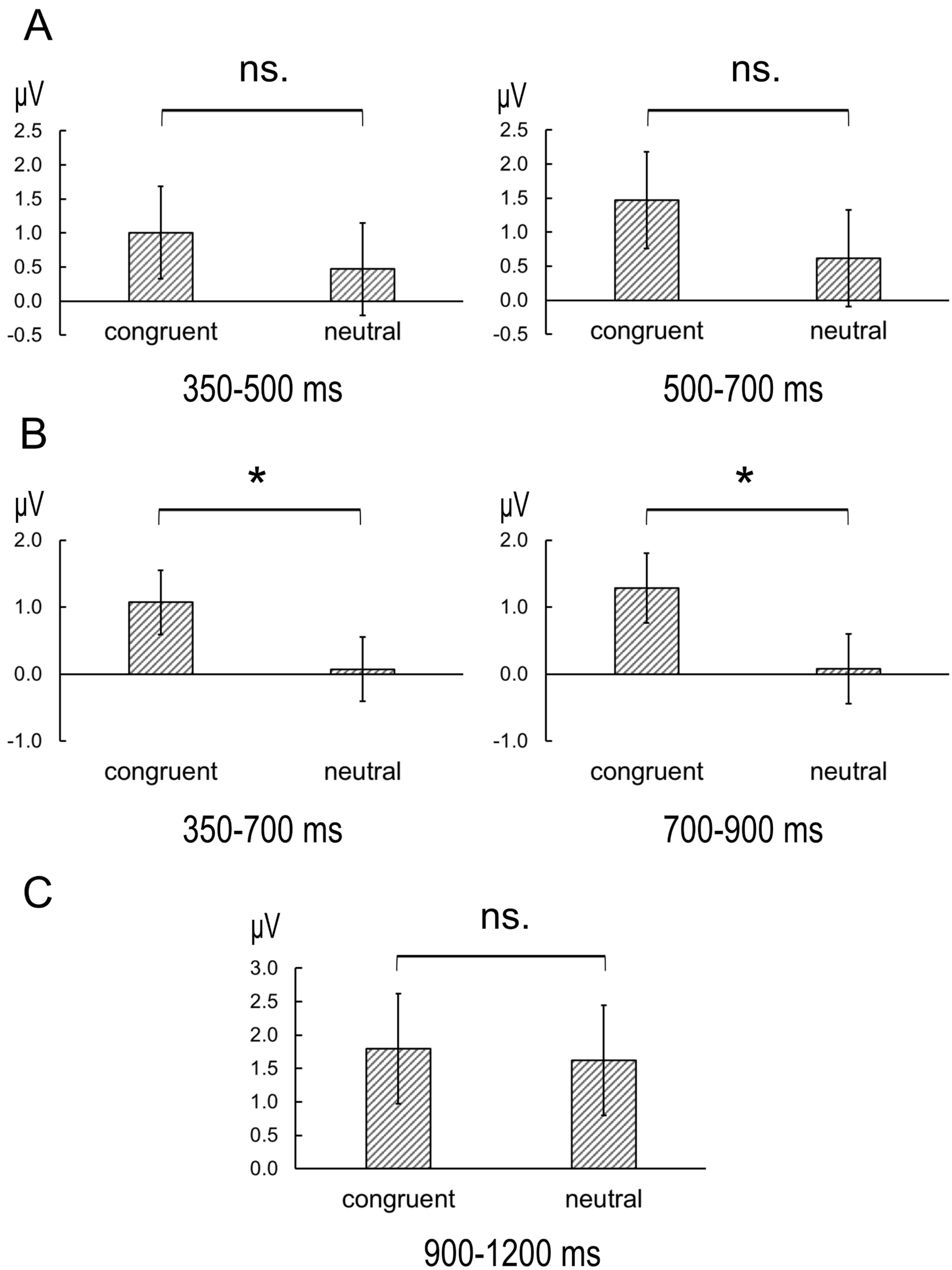

Fig. 5. ERP Amplitudes of Subsequent Memory Effects. Panel A shows hit minus miss-mean amplitude measures for the N400 cluster in the earlier (350–500 ms) and the later (500–700 ms) N400 time window in each condition. Hit minus miss-mean amplitude measures of the parietal SME in the earlier (350–700 ms) and the later (700–900 ms) time window in the parietal cluster are illustrated in Panel B, for each condition, separately. Panel C shows the hit minus miss-mean amplitude measures in each condition for the frontal cluster from 900 to 1200 ms. The asterisk marks statistically significant effects ($p < .05$). Error bars represent +/- 1 standard error of the mean difference for the across-conditions comparison in all diagrams.

effect of congruency, *Pillai* = 0.46, $F(1, 29) = 25.00$, $p < .001$, a significant main effect of memory, *Pillai* = 0.17, $F(1, 29) = 5.98$, $p = .021$, and a significant interaction of congruency and memory, *Pillai* = 0.16, $F(1, 29) = 5.34$, $p = .028$. To resolve the significant interaction, Bonferroni-Holm-corrected, follow-up paired-samples *t* tests on subsequent memory were calculated for the congruent and the neutral condition, separately. This analysis revealed a significant parietal subsequent memory effect in the congruent condition, $t(29) = 3.00$, $p = 0.010$ (two-sided), $g_{av} = 0.44$, but not in the neutral condition, $t(29) = 0.24$, $p = .811$ (two-sided), $g_{av} = 0.03$ (see Fig. 5). Thus, comparable to the earlier parietal SME (350–700 ms), the parietal SME in this later time window was modulated by congruency.

4.3.6. Topographical profile analyses.

To explore whether the topographic profiles of N400 congruency effects and subsequent memory effects differ qualitatively, and not merely in relative strength (Urbach & Kutas, 2002; 2006), we vector-scaled the data according to McCarthy and Wood (1985) and calculated Effect × Anteriority × Laterality-MANOVAs for the respective effects and time windows. We report only significant effects including the effect factor. Here, we were particularly interested in three topographical contrasts: (A) the contrast between the condition-unspecific N400-SME and the N400 congruency effect (in the N400 and post-N400 time interval), (B) the contrast between the parietal SME in the congruent condition and the N400 congruency effect (in the N400 and post-N400 time interval) (C) the frontal SME (collapsed across both levels of congruency) and the parietal SME.

To calculate congruency effects, the mean amplitude difference between congruent and neutral trials was computed for each participant and time window, separately. To calculate SMEs, mean amplitudes for forgotten trials were subtracted from mean amplitudes for remembered trials. Thereafter, all scores were vector-scaled. In the following analyses, only significant effects including the effects factor are reported.

A: With this first contrast, we examined whether the spatial distribution of the N400-SME is comparable to the spatial distribution of the N400 congruency effect, which, together with their similar temporal characteristics, would support the assumption that the N400-SME is indeed functionally equivalent with the N400 effect. MANOVAs with the factors effect (N400-SME, N400 congruency effect), antPos (anterior, central, posterior) and laterality (left, mid, right) did not reveal significant three-way interactions, neither in the N400, $Pillai = 0.08$, $F(4, 26) = 0.55$, $p = .698$, nor in the post-N400 time interval, $Pillai = 0.17$, $F(4, 26) = 1.30$, $p = .297$. No other interaction including the effects factor approached significance. Thus, there is no evidence for different topographic distributions of the N400-SME and the N400-congruency effect, and thus no empirical evidence for functionally independent ERPs in both time intervals.

B: Next, we aimed to investigate whether the parietal SME and the N400 congruency effect differ in their topographic profiles, what, together with their different temporal expansion, would support the assumption that the parietal SME and the N400 congruency effect differ functionally. For the parietal SME in the congruent condition, we chose the time window from 700 to 900 ms, because the effect was largest in this time window. MANOVAs with the factors effect (congruent parietal SME, N400 congruency effect), antPos (anterior, central, posterior) and laterality (left, mid, right) revealed a marginal significant three-way interaction, $Pillai = 0.30$, $F(4, 26) = 2.72$, $p = .051$ in the N400 time interval and a significant three-way interaction in the post-N400 time window, $Pillai = 0.44$, $F(4, 26) = 5.20$, $p = .003$. Thus, the parietal SME in the congruent condition differs qualitatively in its topographic profile from the N400 congruency effect in both N400 time intervals.

C: Lastly, we aimed to test if the parietal SME in the congruent condition (700–900 ms) and the late frontal SME (900–1200 ms, collapsed across both levels of congruency) differ in their topographic profiles, providing evidence against the parietal SME being a mere continuation of the frontal SME. An Effect (congruent parietal SME, late frontal SME) × AntPos (anterior, central, posterior) × Laterality (left, mid, right)-MANOVA revealed a significant three-way interaction $Pillai = 0.32$, $F(4, 26) = 3.12$, $p = .032$, suggesting that the topographic profiles of the parietal and frontal SMEs differ, as well. To summarize: While we did not find topographical differences between the N400-SME and the N400-congruency effect as well as between the extended N400 SME and the extended N400 congruency effect, the parietal SME in the congruent condition could be topographically differentiated from the N400-congruency effect, the extended N400 congruency effect and the late frontal SME.

5. Discussion

An extensive number of studies have demonstrated that events that are congruent with a given schema are remembered better than incongruent events. However, the mechanisms by which prior semantic knowledge facilitates episodic encoding of new information still need to be specified. In the present study, we extend the schema framework to the learning of novel word associations, i.e., compound words, and explored whether schema knowledge supports the encoding of two previously unrelated words. We manipulated the semantic relationship between novel compound words and a fictional definition, from which we assume that it fulfills the requirements of a schema. Thus, we explored whether and how a strong semantic relationship between the schema context and the compound word constituents contributes to episodic memory formation.

5.1. Behavioral results

The finding that events that are congruent with a given schema are remembered better is well established in the neuropsychological literature, and this congruency effect has been reported for a wide range of tasks and modalities (e.g., Bein et al., 2014; Pichert & Anderson, 1977; Staresina et al., 2009; van Kesteren et al., 2013). Whilst most of these studies focus on the learning of single items, several studies reported beneficial effects of schema-congruency for the learning of associations (e.g., Bein et al., 2014; Staresina et al., 2009; van Kesteren et al., 2013). The current study focusses on the learning of novel word associations, i.e., novel compound words. In this setting, the constituting items are already known and integrated into prior knowledge structures whilst a novel association between these items must be acquired. Further, the current study embeds the semantic congruency manipulation in a rich linguistic context, which we argue is a more ecologically valid operationalization of semantic knowledge use as e.g., word-color associations (Staresina et al., 2009).

The memory advantage for schema-congruent events in the congruent condition, which we found in the present study, is well in line with the putative easier integration of information that matches representations in semantic memory. This might in turn lead to richer and more elaborated memory traces, which are better accessible in a subsequent memory test (Craik & Tulving, 1975). To ensure that participants could not solve the memory task by relying on item information only, i.e., by assessing the memory strength of the compound constituents, but were enforced to remember the exact combination of the word constituents, recombined compound words were presented during the test phase (together with not yet presented compound words). The finding that between-condition differences were larger for hits than for false alarms to recombined pairs suggests that the congruent context did not just induce a bias to endorse already presented single words as “old” by means of item memory, but rather boosts episodic encoding of the underlying association. How exactly schema congruency fosters the creation of an associative memory representation, e.g., by creating a semantic link between underlying concepts (Boutonnet et al., 2014) cannot be determined based on data from the current study.

5.2. The N400 and the extended N400 congruency effect

In the current study, we found the expected N400 effect from 350 to 500 ms post-stimulus, i.e., an attenuation of the N400 in the congruent condition relative to the neutral condition. This effect is consistent with a large number of studies showing similar semantic congruency effects for the N400 (Bridger et al., 2012; DeLong et al., 2005; Kutas & Hillyard, 1980; Van Petten & Luka, 2012; see Kutas & Federmeier, 2011 for a review).

It could be argued that the two context conditions did not only differ in the semantic congruency between the definition and the compound word, but also in the amount of semantic content of the definitions themselves. Congruent contexts may have been richer in content and thus may have allowed to better predict the target words (see Federmeier et al., 2007, as an example) and these differences may have facilitated semantic processing and boosted episodic encoding of the compound words. To test whether both context types differed in their predictability, we conducted an additional rating study[6] in which we presented congruent and neutral definitions without the compound word and asked participants to indicate how well they could imagine something from the definition. The rationale behind this approach was to check if the congruent condition induces more constraint and thus predictive potential than the neutral condition, when presented without the compound word. As a cloze study is not suitable to estimate constraint for novel compound words, constraint was operationalized as imageability, i.e., how well someone could imagine something from the definition. As there was no significant difference between conditions for these ratings, $t(239) = 1.90$, $p = .058$, $g_{av} = 0.15$ ($M_{congruent} = 2.97$, $SD = 0.47$, $M_{neutral} = 3.04$, $SD = 0.45$), with an opposite numerical trend, we conclude that differences in the predictability of the compound words between conditions (as operationalized in this rating study) cannot account for the N400 effects. As this alternative explanation can be ruled out based on these data, we feel safe to interpret the N400 as a result of facilitated semantic processing of the compound words, due to the preceding definition.

Of note, an N400-congruency effect (350–500 ms) was not found when subsequent memory was considered in the analysis. Critically, subsequent memory ERPs only included trials of compound words that were presented identically during the test phase (intact compound words), automatically halving the number of potentially to-be-analyzed trials. This reduction in the signal-to-noise ratio might have prevented the detection of the effect. However, as the N400 congruency effect in the current study is in line with a plethora of studies on semantic priming and the N400 (e.g., Boutonnet et al., 2014; Holcomb, 1993), we deem it as a reliable measure of semantic congruency.

Visual inspection of the waveforms revealed an additional, extended N400 congruency effect following the N400. A post-hoc analysis on this effect (500–700 ms) revealed more positive amplitudes in the congruent, as compared to the neutral condition, with similar polarity and distribution as the N400. Although it is not possible to identify this effect as an additional N400 effect based on the data at hand, it is tempting to speculate that the temporal extension of the N400 could be the result of the combinatorial processing of the compound word constituents that is required to compute a whole-word meaning. Dual-route approaches of compound word processing (Isel et al., 2003; Koester et al., 2007; Koester et al., 2004; Sandra, 1990; Zwitserlood, 1994; Libben, 2006) assume that already established compound words may be represented in a single lexical entry or are decomposed and analyzed as individual constituents via combinatorial mechanisms. These processes occur in a parallel fashion (e.g., Caramazza et al., 1988). As the compound words in the present study are novel, there cannot yet exist an accessible lexical entry (Libben, 2006). Accordingly, we assume that all novel compound words in the current study must be decomposed, and the conceptual representations of its constituents must be accessed in order to be integrated to a whole word meaning (see Gagné & Spalding, 2009). Interestingly, there is evidence that the N400 is sensitive to this form of lexical-semantic integration of compound word constituents (Koester et al., 2007; 2009). Thus, the cumbersome semantic processing of the novel compound words, i.e., the retrieval of conceptual information of the constituents from long-term memory and its semantic integration, might provide an explanation for an extended N400 effect in the current study. Unfortunately, to the best of our knowledge, there is no study directly investigating the temporal characteristics of processing of novel compound words with ERPs in the visual domain. Thus, this topic should be addressed in future studies.

5.3. Subsequent memory modulations of the N400 and the extended N400 congruency effect

Interestingly, in the present study, we found evidence that the semantic facilitation, reflected by the N400 effect, contributes to successful memory formation, as there was an N400-SME in both context conditions, which did not differ from the N400 congruency effect in its scalp topography. A similar N400-SME was obtained for a schema congruency manipulation in Neville et al. (1986), although in this latter study, the N400-SME was modulated by congruency (i.e., larger in the congruent condition). However, as this analysis was based on data from a very small sample ($n = 5$), these results should be interpreted with caution.

Critically, as the N400-SME in the current study did not vary across conditions, it cannot account for the behavioral memory advantage in the congruent condition. This complicates its functional interpretation at first glance. However, as we already argued above, the N400 has also been found to be sensitive to the ease of semantic integration of compound word constituents (Koester et al., 2007; 2009). Semantic integration might have been facilitated by priming effects of the head noun in both contexts and the modifier noun in the congruent context. The ease of semantic integration of the constituents might benefit memory formation and this would then be reflected in the N400-SME. The attentive reader might wonder why the N400-SME is then not larger in the congruent condition, where there is the additional modifier priming effect next to the context-independent head priming effect. Theories on conceptual combination of modifier-head phrases assume that the modifier is used to retrieve information about which type of thematic relationship is frequently used when this word is used as a modifier, whereby the head is used to select from competing relations (Gagné, 2002). Thus, the data of the current study might suggest that only head priming is reflected in the N400-SME, probably indicating the facilitated selection of a fitting relation, whereby it remains unclear why the additional modifier priming in the congruent condition is not reflected in larger N400-SMEs.

However, semantic integration of the novel compound words might have been influenced by other factors. The Competition Among Relations in Nominals (CARIN) theory (Gagné & Shoben, 1997; Gagné, 2002) assumes that to compute the meaning of a modifier-noun phrase, concepts are combined by selecting an adequate relation linking both concepts. Here, several possible relations can be distinguished, as e.g., *made of*: snowball is a ball made of snow (Gagné & Spalding, 2009). Which relations come into consideration when a combination is encountered is determined by the modifier. It is assumed that the modifier contains information about the frequency with which it is used within a particular relation in already known conceptual combinations, i.e., a relational distribution. A modifier's relational distribution influences how easy a combination is interpreted, whereby high-frequency relations are easier to interpret than low-frequency relations (Gagné, 2002). Whereas the modifier determines which relations are considered, the head noun is used to validate competing relations (Gagné, 2002). Critically, albeit relation availability is influenced by the predictability of an additionally presented linguistic context, pre-existing differences in relation availability are not overridden by the context (Gagné &

[6] The rating study was conducted online, generated using SoSci Survey (Leiner, 2019) and was made available to users via https://s2survey.net. A sample of $N = 24$ participants took part in the study. Therefore, two lists were created in which 120 fictional definitions were presented in their congruent version and the remaining 120 fictional definitions in their neutral version. The assignment of the congruent or neutral version of the definition was counterbalanced across lists and list assignment was counterbalanced across participants so that each definition in each version was rated by $n = 12$ participants. Participants saw the sentences without "is called", but instead completed with three dots (e.g., "Eine Sitzgelegenheit, die in einem Planetarium steht…", *A seat, one can find in a planetary…*) and had to indicate how well they could imagine something from the definition on a four-point scale, ranging from "not at all" to "absolutely". No time limit was given and items could not be skipped.

Spalding, 2004). Following Middleton et al. (2011), this approach is referred to as the *generation hypothesis*, i.e., “that the initial interpretation of novel combinations in context is based on the generation of a meaning” (p. 809), which is influenced by modifier relation frequency. An alternative approach, *the anaphor resolution hypothesis*, assumes that when a context is present, it is first attempted to link the combination to a referent in the context and sense generation, in terms of the *generation hypothesis*, is only engaged if no referent is provided by the discourse (Middleton et al., 2011, cf. Gerrig & Bortfeld, 1999).

However, Middleton et al. (2011) provide empirical evidence in favor of a third account, the *dual-process hypothesis*, that assumes that when a compound word is encountered with a context, sense generation, based on the constituents, and context-driven anaphor resolution, i.e., linking the combination to an earlier discourse referent provided by a context, run in parallel and “either or both may inform the initial interpretation of a novel combination in context” (p. 809). Consistent with the *dual-process hypothesis*, the N400-SME might reflect memory-relevant but context-independent differences in the ease of semantic integration of the compound words via sense generation, i.e., the availability of modifier relation information and morpho-semantic knowledge about the head noun, required to select an adequate relation. The fact that the same compound words with their modifier relation frequency distributions were used in both context conditions might explain the context-independency of the N400-SME. In contrast, the simultaneously onsetting and long-lasting parietal SME probably reflects context-dependent processes as involved in *context-driven anaphor resolution*, i.e., linking the combination to an earlier discourse referent, provided by the context, in the service of memory formation. This fits well with the context-dependency of the parietal SME.

5.4. The early parietal subsequent memory effect

The parietal SME was larger for compound words that were preceded by a congruent, compared to a neutral context. This effect emerged at approximately 350 ms and reached largest amplitudes in the time window from 700 to 900 ms. Notably, the N400 effect, as well as the extended N400 effect and the parietal SME in the 700 to 900 ms time interval showed qualitatively distinct scalp topographies, which suggests that both effects can be functionally dissociated.

This finding resembles the results of the Kamp et al. (2017) study, which explored the learning of associations using a definition-sentence paradigm (e.g., Bader et al., 2010; Quamme et al., 2007; Wiegand et al., 2010). As compared to this study, in which the relationship between a congruent context and the compound word was only broadly defined (Kamp et al., 2017), we carefully manipulated schema congruency as the semantic relationship (verified in a rating study) between a fictional definition and the modifier constituent of the novel compound word (congruent context condition) and included a neatly matched neutral control condition. As a similar SME was found also only for words which were congruent with a preceding category cue in a recent study on schema-based learning (Höltje et al., 2019), the parietal SME might reflect some form of integration of semantic information with congruent events in the service of successful memory encoding. The present results confirm and extend these findings in showing that schema-based learning boosts not only learning of single items, but also learning of associations by means of similar mechanisms.

We argue that there are at least two different processing mechanisms, which might account for the parietal SME. Subsequent memory effects with similar temporal and spatial characteristics have been reported in memory tasks probing memory for single items or item-specific details (Kamp et al., 2017; Karis et al., 1984) or memory for stimuli which are distinctive in their processing context (Fabiani & Donchin, 1995), like emotionally negative items (Kamp et al., 2015) or pictorial stimuli which are retrieved based on verbal probes (Gonsalves & Paller, 2000). These parietal SMEs have been originally described as modulations of the P300 (Sutton et al., 1965). It has been shown that low probability events elicit a P300 and, probably due to their distinctiveness, are later better remembered (Fabiani et al., 1986; Karis et al., 1984), i.e., the von Restorff effect (von Restorff, 1933). However, this distinctiveness explanation of the parietal SME is more plausible when isolated events must be processed, which is not the case in the present study. However, the congruent condition provides a better framework to integrate the meaning of both compound word constituents into a joint, single item representation than the neutral condition. Thus, it is possible that the selective parietal SME in the congruent condition reflects the item-specific processing of the novel compound word, resulting in a single item representation.

Alternatively, it is also conceivable that the parietal SME reflects processes normally indicative for the P600. The P600 is a positive ERP component with a centro-parietal distribution that onsets between 500 and 1000 ms after the onset of the critical word and has originally been related to syntactic processing during language comprehension (Friederici et al., 2002; Hagoort et al., 1993; Osterhout & Holcomb, 1992). This functional interpretation of the P600 has been refined recently, as the P600 has also been observed for forms of semantic processing, as in joke comprehension (Coulson & Kutas, 2001), irony (Regel et al., 2011) and the processing of metaphors (Bambini et al., 2016). In their Retrieval Integration (RI) account, Brouwer et al. (2012) assume that the P600 reflects the “construction, revision, or updating of a mental representation of what is being communicated” (Brouwer et al., 2012, p.137). Thus, the P600 might reflect prolonged attempts to make sense of an input that initially produced a conflict (Kuperberg et al., 2020). We argue that variations of the P600 could account for the parietal SME in the congruent condition, as similar to metaphors; the literal meaning of the compound word must be overridden in favor of the whole word meaning provided by the context. In doing so, the novel whole-word concept is created and mapped onto the word form of the novel compound word, updating its mental representation. These processes are only initiated in the congruent condition, where it is possible to integrate the conceptual combination into prior knowledge structures by creating a conceptual compound representation, which could be beneficial for memory formation, and which is not the case in the neutral condition.

The more positive waveforms for subsequently remembered versus forgotten compound words, i.e., parietal SME, is consistent with both a P300 and a P600 view. However, a P600 interpretation of the parietal SME fits well with schema-based learning as it might be a direct correlate of the integration of the word constituents into the schema representation. To conclude, both presented explanations might account for the parietal SME but the contributions of the processes underlying the P300 and the P600 to the parietal SME cannot be disentangled in the current study and should be addressed in future studies. Moreover, these approaches are not mutually exclusive, as there is an ongoing debate in psycholinguistics whether the family of P600 positivities belongs to the wider P3 family (Friederici et al., 2001; Osterhout et al., 1996). According to a recent account, the P600 might mark the “point in time where a linguistic entity has achieved subjective significance and some form of adaption process is underway” (Sassenhagen et al., 2014, p. 37). However, these considerations are beyond the scope of this article.

Another important topic, which should be addressed in future research, is how the discussed processes reflected in the parietal SME relate to neuroanatomical models of schema-based learning. Even though inferences from scalp ERPs on underlying brain structures are difficult to draw, it is tempting to speculate that the parietal SME, consistently found when schema-congruent information is successfully encoded, is an electrophysiological correlate of the lower mPFC activity and/or the weaker connectivity between the mPFC and the hippocampus, observed in brain imaging studies when schema-congruent information is encoded (van Kesteren et al., 2010).

5.5. The late frontal subsequent memory effect

While an SME in the 700 to 900 ms time interval was present only in the congruent condition, in a still later time interval (900–1200 ms), more positive going waveforms for hits than for misses were obtained irrespective of the encoding condition. Kamp et al. (2017) reported a similarly late and frontally distributed SME that was not affected by encoding condition. With its clear frontal topography, this effect differs clearly from the preceding parietal SME. Moreover, as it was indistinguishable between the two encoding conditions, it presumably reflects processes in brain networks that contribute equally to successful encoding in both conditions. As the late and frontally distributed SME has frequently been observed when relations between arbitrary items had to be encoded (Kamp et al., 2017; Karis et al., 1984; Mecklinger & Müller, 1996), it has been taken as an index of more general successful inter-item encoding. Alternatively, these late effects could reflect post-encoding mnemonic processing like the reactivation of memory traces or the transformation of working memory representations in long-term memory (Cohen et al., 2015).

6. Conclusion

In the present study, we investigated the mechanisms by which prior semantic knowledge facilitates episodic encoding of new information and extend the schema framework to the learning of novel compound words. We found superior associative memory performance in the schema-congruent context condition, as compared to the neutral condition. Analyses of event-related potentials revealed an N400 effect that extended in a post-N400 time interval (500 to 700 ms). The N400-SME and the post-N400 SME did not differ across conditions and this pattern of results is interpreted in that the processes reflected in the N400-SME reflect semantic integration of the pre-activated concepts of the constituents, irrespective of context. In a later time-interval, an SME with a parietal distribution was larger for words preceded by a congruent context. This effect, which we link to the schema-supported formation of a conceptual compound representation, could also account for the superior memory performance in the congruent context condition. An additional late frontal SME was present in both conditions and might reflect inter-item binding of the underlying compound word constituents and their respective fictional contexts (Kamp et al., 2017).

CRediT authorship contribution statement

Julia A. Meßmer: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Validation, Visualization, Writing – original draft, Writing – review & editing. **Regine Bader:** Conceptualization, Methodology, Resources, Supervision, Validation, Writing – review & editing. **Axel Mecklinger:** Conceptualization, Funding acquisition, Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Alba, J. W., & Hasher, L. (1983). Is memory schematic? *Psychological Bulletin, 93*(2), 203–231.

Atienza, M., Crespo-Garcia, M., & Cantero, J. L. (2011). Semantic Congruence Enhances Memory of Episodic Associations: Role of Theta Oscillations. *Journal of Cognitive Neuroscience, 23*(1), 75–90. https://doi.org/10.1162/jocn.2009.21358

Bader, R., Mecklinger, A., Hoppstädter, M., & Meyer, P. (2010). Recognition memory for one-trial-unitized word pairs: Evidence from event-related potentials. *NeuroImage, 50*(2), 772–781. https://doi.org/10.1016/j.neuroimage.2009.12.100

Bader, R., Opitz, B., Reith, W., & Mecklinger, A. (2014). Is a novel conceptual unit more than the sum of its parts?: FMRI evidence from an associative recognition memory study. *Neuropsychologia, 61*, 123–134. https://doi.org/10.1016/j.neuropsychologia.2014.06.006

Bambini, V., Bertini, C., Schaeken, W., Stella, A., & DiRusso, F. (2016). Disentangling Metaphor from Context: An ERP Study. *Frontiers in Psychology, 7*, Article 559. https://doi.org/10.3389/fpsyg.2016.00559

Bartlett, F. C. (1932). *Remembering: A Study in Experimental and Social Psychology*. Cambridge University Press.

Bein, O., Livneh, N., Reggev, N., Gilead, M., Goshen-Gottstein, Y., & Maril, A. (2015). Delineating the Effect of Semantic Congruency on Episodic Memory: The Role of Integration and Relatedness. *PLOS ONE, 10*(2), e0115624. https://doi.org/10.1371/journal.pone.0115624

Bein, O., Reggev, N., & Maril, A. (2014). Prior knowledge influences on hippocampus and medial prefrontal cortex interactions in subsequent memory. *Neuropsychologia, 64*, 320–330. https://doi.org/10.1016/j.neuropsychologia.2014.09.046, 222.

Boutonnet, B., McClain, R., & Thierry, G. (2014). Compound words prompt arbitrary semantic associations in conceptual memory. *Frontiers in Psychology, 5*. https://doi.org/10.3389/fpsyg.2014.00222

Bridger, E. K., Bader, R., Kriukova, O., Unger, K., & Mecklinger, A. (2012). The FN400 is functionally distinct from the N400. *NeuroImage, 63*(3), 1334–1342. https://doi.org/10.1016/j.neuroimage.2012.07.047

Brothers, T., Wlotko, E. W., Warnke, L., & Kuperberg, G. R. (2020). Going the Extra Mile: Effects of Discourse Context on Two Late Positivities During Language Comprehension. *Neurobiology of Language, 1*(1), 135–160. https://doi.org/10.1162/nol_a_00006

Brouwer, H., Fitz, H., & Hoeks, J. (2012). Getting real about Semantic Illusions: Rethinking the functional role of the P600 in language comprehension. *Brain Research, 1446*, 127–143. https://doi.org/10.1016/j.brainres.2012.01.055

Caramazza, A., Laudanna, A., & Romani, C. (1988). Lexical access and inflectional morphology. *Cognition, 28*(3), 297–332.

Cohen, N., Pell, L., Edelson, M. G., Ben-Yakov, A., Pine, A., & Dudai, Y. (2015). Peri-encoding predictors of memory encoding and consolidation. *Neuroscience & Biobehavioral Reviews, 50*, 128–142. https://doi.org/10.1016/j.neubiorev.2014.11.002

Coulson, S., & Kutas, M. (2001). Getting it: Human event-related brain response to jokes in good and poor comprehenders. *Neuroscience Letters, 316*(2), 71–74. https://doi.org/10.1016/S0304-3940(01)02387-4

Craik, F. I. M., & Tulving, E. (1975). Depth of processing and the retention of words in episodic memory. *Journal of Experimental Psychology: General, 104*(3), 268–294.

DeLong, K. A., Urbach, T. P., & Kutas, M. (2005). Probabilistic word pre-activation during language comprehension inferred from electrical brain activity. *Nature Neuroscience, 8*(8), 1117–1121. https://doi.org/10.1038/nn1504

Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods, 134*(1), 9–21. https://doi.org/10.1016/j.jneumeth.2003.10.009

Dien, J., & Santuzzi, A. M. (2005). Application of repeated measures ANOVA to high-density ERP datasets: A review and tutorial. In T. C. Handy (Ed.), *Event-related potentials: A methods handbook* (pp. 57–82). MIT Press.

Fabiani, M., & Donchin, E. (1995). Encoding Processes and Memory Organization: A Model of the von Restorff Effect. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*(1), 224–240.

Fabiani, M., Karis, D., & Donchin, E. (1986). P300 and Recall in an Incidental Memory Paradigm. *Psychophysiology, 23*(3), 298–308.

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods, 41*(4), 1149–1160. https://doi.org/10.3758/BRM.41.4.1149

Federmeier, K. D., Wlotko, E. W., De Ochoa-Dewald, E., & Kutas, M. (2007). Multiple effects of sentential constraint on word processing. *Brain Research, 1146*, 75–84. https://doi.org/10.1016/j.brainres.2006.06.101

Field, A. (2009). Discovering Statistics Using IBM SPSS Statistics. SAGE Publications.

Friederici, A. D., Hahne, A., & Saddy, D. (2002). Distinct Neurophysiological Patterns Reflecting Aspects of Syntactic Complexity and Syntactic Repair. *Journal of Psycholinguistic Research, 31*(1), 45–63.

Friederici, A. D., Mecklinger, A., Spencer, K. M., Steinhauer, K., & Donchin, E. (2001). Syntactic parsing preferences and their on-line revisions: A spatio-temporal analysis of event-related brain potentials. *Cognitive Brain Research, 11*(2), 305–323. https://doi.org/10.1016/S0926-6410(00)00065-3

Gagné, C. L. (2002). Lexical and Relational Influences on the Processing of Novel Compounds. *Brain and Language, 81*(1–3), 723–735. https://doi.org/10.1006/brln.2001.2559

Gagné, C. L., & Shoben, E. J. (1997). Influence of Thematic Relations on the Comprehension of Modifier-Noun Combinations. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23*(1), 71–87.

Gagné, C. L., & Spalding, T. L. (2004). Effect of discourse context and modifier relation frequency on conceptual combination. *Journal of Memory and Language, 50*(4), 444–455. https://doi.org/10.1016/j.jml.2004.01.003

Gagné, C. L., & Spalding, T. L. (2009). Constituent integration during the processing of compound words: Does it involve the use of relational structures? *Journal of Memory and Language, 60*(1), 20–35. https://doi.org/10.1016/j.jml.2008.07.003

Gerrig, R. J., & Bortfeld, H. (1999). Sense Creation in and out of Discourse Contexts. *Journal of Memory and Language, 41*(4), 457–468. https://doi.org/10.1006/jmla.1999.2656

Gibney, K. D., Kypriotakis, G., Cinciripini, P. M., Robinson, J. D., Minnix, J. A., & Versace, F. (2020). Estimating statistical power for event-related potential studies using the late positive potential. *Psychophysiology, 57*, Article e13482. https://doi.org/10.1111/psyp.13482

Gilboa, A., & Marlatte, H. (2017). Neurobiology of Schemas and Schema-Mediated Memory. *Trends in Cognitive Sciences, 21*(8), 618–631. https://doi.org/10.1016/j.tics.2017.04.013

Gonsalves, B., & Paller, K. A. (2000). Neural Events that underlie remembering something that never happened. *Nature Neuroscience, 3*(12), 1316–1321.

Graf, P., & Schacter, D. L. (1989). Unitization and grouping mediate dissociations in memory for new associations. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15*(5), 930–940. https://doi.org/10.1037/0278-7393.15.5.930

Greve, A., Cooper, E., Tibon, R., & Henson, R. N. (2019). Knowledge is power: Prior knowledge aids memory for both congruent and incongruent events, but in different ways. *Journal of Experimental Psychology: General, 148*(2), 325–341. https://doi.org/10.1037/xge0000498

Hagoort, P., Brown, C., & Groothusen, J. (1993). The syntactic positive shift (sps) as an ERP measure of syntactic processing. *Language and Cognitive Processes, 8*(4), 439–483. https://doi.org/10.1080/01690969308407585

Hall, D. M., & Geis, M. F. (1980). Congruity and Elaboration in Free and Cued Recall. *Journal of Experimental Psychology: Human Learning and Memory, 6*(6), 778–784.

Häuser, K. I., Demberg, V., & Kray, J. (2019). Effects of aging and dual-task demands on the comprehension of less expected sentence continuations: Evidence from Pupillometry. *Frontiers in Psychology, 10*, Article 709. https://doi.org/10.3389/fpsyg.2019.00709

Heister, J., Würzner, K.-M., Bubenzer, J., Pohl, E., Hanneforth, T., Geyken, A., & Kliegl, R. (2011). DlexDB – eine lexikalische Datenbank für die psychologische und linguistische Forschung. *Psychologische Rundschau, 62*(1), 10–20. https://doi.org/10.1026/0033-3042/a000029

Holcomb, P. J. (1993). Semantic priming and stimulus degradation: Implications for the role of the N400 in language processing. *Psychophysiology, 30*(1), 47–61. https://doi.org/10.1111/j.1469-8986.1993.tb03204.x

Holm, S. (1979). A Simple Sequentially Rejective Multiple Test Procedure. *Scandinavian Journal of Statistics, 6*(2), 65–70.

Höltje, G., Lubahn, B., & Mecklinger, A. (2019). The congruent, the incongruent, and the unexpected: Event-related potentials unveil the processes involved in schematic encoding. *Neuropsychologia, 131*, 285–293. https://doi.org/10.1016/j.neuropsychologia.2019.05.013

Isel, F., Gunter, T. C., & Friederici, A. D. (2003). Prosody-assisted head-driven access to spoken German compounds. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29*(2), 277–288. https://doi.org/10.1037/0278-7393.29.2.277

Jasper, H. (1958). Report of the committee on methods of clinical examination in electroencephalography. *Electroencephalography and Clinical Neurophysiology, 10*(2), 370–375. https://doi.org/10.1016/0013-4694(58)90053-1

Kamp, S.-M. (2020). Neurocognitive mechanisms of guided item and associative encoding in young and older adults. *Brain and Cognition, 145*, 105626. https://doi.org/10.1016/j.bandc.2020.105626

Kamp, S.-M., Bader, R., & Mecklinger, A. (2017). ERP Subsequent Memory Effects Differ between Inter-Item and Unitization Encoding Tasks. *Frontiers in Human Neuroscience, 11*, Article 30. https://doi.org/10.3389/fnhum.2017.00030

Kamp, S.-M., Potts, G. F., & Donchin, E. (2015). On the roles of distinctiveness and semantic expectancies in episodic encoding of emotional words. *Psychophysiology, 52*(12), 1599–1609. https://doi.org/10.1111/psyp.12537

Karis, D., Fabiani, M., & Donchin, E. (1984). "P300" and memory: Individual differences in the von Restorff effect. *Cognitive Psychology, 16*(2), 177–216. https://doi.org/10.1016/0010-0285(84)90007-0

Koester, D., Gunter, T. C., & Wagner, S. (2007). The morphosyntactic decomposition and semantic composition of German compound words investigated by ERPs. *Brain and Language, 102*(1), 64–79. https://doi.org/10.1016/j.bandl.2006.09.003

Koester, D., Gunter, T. C., Wagner, S., & Friederici, A. D. (2004). Morphosyntax, Prosody, and Linking Elements: The Auditory Processing of German Nominal Compounds. *Journal of Cognitive Neuroscience, 16*(9), 1647–1668. https://doi.org/10.1162/0898929042568541

Koester, D., Holle, H., & Gunter, T. C. (2009). Electrophysiological evidence for incremental lexical-semantic integration in auditory compound comprehension. *Neuropsychologia, 47*(8-9), 1854–1864. https://doi.org/10.1016/j.neuropsychologia.2009.02.027

Kuperberg, G. R., Brothers, T., & Wlotko, E. W. (2020). A Tale of Two Positivities and the N400: Distinct Neural Signatures Are Evoked by Confirmed and Violated Predictions at Different Levels of Representation. *Journal of Cognitive Neuroscience, 32*(1), 12–35. https://doi.org/10.1162/jocn_a_01465

Kutas, M., & Federmeier, K. D. (2011). Thirty Years and Counting: Finding Meaning in the N400 Component of the Event-Related Brain Potential (ERP). *Annual Review of Psychology, 62*(1), 621–647. https://doi.org/10.1146/psych.2011.62.issue-110.1146/annurev.psych.093008.131123

Kutas, M., & Hillyard, S. (1980). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science, 207*(4427), 203–205. https://doi.org/10.1126/science.7350657

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for t-tests and ANOVAs. *Frontiers in Psychology, 4*. Article 863.

Leiner, D. J. (2019). SoSci Survey (Version 3.1.06) [Computer software]. Available at https://www.soscisurvey.de.

Libben, G. (2006). Why study compound processing? An overview of the issues. In G. Libben & G. Jarema (Eds.), The Representation and Processing of Compound Words (pp. 1-22). Oxford Linguistics.

Lopez-Calderon, J., & Luck, S. J. (2014). ERPLAB: An open-source toolbox for the analysis of event-related potentials. Frontiers in Human Neuroscience, 8, Article 213. DOI: 10.3389/fnhum.2014.00213.

McCarthy, G., & Wood, C. C. (1985). Scalp distributions of event-related potentials: An ambiguity associated with analysis of variance models. *Electroencephalography and clinical Neurophysiology, 62*(3), 203–208.

Mecklinger, A., & Müller, N. (1996). Dissociations in the Processing of "What" and "Where" Information in Working Memory: An Event-Related Potential Analysis. *Journal of Cognitive Neuroscience, 8*(5), 453–473. https://doi.org/10.1162/jocn.1996.8.5.453

Middleton, E. L., Rawson, K. A., & Wisniewski, E. J. (2011). How do we process novel conceptual combinations in context? *Quarterly Journal of Experimental Psychology, 64*(4), 807–822. https://doi.org/10.1080/17470218.2010.520414

Naghavi, H. R., Eriksson, J., Larsson, A., & Nyberg, L. (2011). Cortical regions underlying successful encoding of semantically congruent and incongruent associations between common auditory and visual objects. *Neuroscience Letters, 505*(2), 191–195. https://doi.org/10.1016/j.neulet.2011.10.022

Neville, H. J., Kutas, M., Chesney, G., & Schmidt, A. L. (1986). Event-related brain potentials during initial encoding and recognition memory of congruous and incongruous words. *Journal of Memory and Language, 25*(1), 75–92.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia, 9*(1), 97–113. https://doi.org/10.1016/0028-3932(71)90067-4

Osterhout, L., & Holcomb, P. J. (1992). Event-related brain potentials elicited by syntactic anomaly. *Journal of Memory and Language, 31*(6), 785–806. https://doi.org/10.1016/0749-596X(92)90039-Z

Osterhout, L., McKinnon, R., Bersick, M., & Corey, V. (1996). On the Language Specificity of the Brain Response to Syntactic Anomalies: Is the Syntactic Positive Shift a Member of the P300 Family? *Journal of Cognitive Neuroscience, 8*(6), 507–526. https://doi.org/10.1162/jocn.1996.8.6.507

Otten, L. J., & Donchin, E. (2000). Relationship between P300 amplitude and subsequent recall for distinctive events: Dependence on type of distinctiveness attribute. *Psychophysiology, 37*(5), 644–661.

Packard, P. A., Rodríguez-Fornells, A., Bunzeck, N., Nicolás, B., de Diego-Balaguer, R., & Fuentemilla, L. (2017). Semantic Congruence Accelerates the Onset of the Neural Signals of Successful Memory Encoding. *The Journal of Neuroscience, 37*(2), 291–301. https://doi.org/10.1523/JNEUROSCI.1622-16.2016

Paller, K. A., Kutas, M., & Mayes, A. R. (1987). Neural correlates of encoding in an incidental learning paradigm. *Electroencephalography and Clinical Neurophysiology, 67*(4), 360–371.

Paller, K. A., & Wagner, A. D. (2002). Observing the transformation of experience into memory. *Trends in Cognitive Sciences, 6*(2), 93–102. https://doi.org/10.1016/S1364-6613(00)01845-3

Parks, T., & McClellan, J. (1972). Chebyshev Approximation for Nonrecursive Digital Filters with Linear Phase. *IEEE Transactions on Circuit Theory, 19*(2), 189–194. https://doi.org/10.1109/TCT.1972.1083419

Pichert, J. W., & Anderson, R. C. (1977). Taking Different Perspectives on a Story. *Journal of Educational Psychology, 69*(4), 309–315.

Picton, T. W., Bentin, S., Berg, P., Donchin, E., Hillyard, S. A., Johnson, R., … Taylor, M. J. (2000). Guidelines for using human event-related potentials to study cognition: Recording standards and publication criteria. *Psychophysiology, 37*(2), 127–152. https://doi.org/10.1111/psyp.2000.37.issue-210.1111/1469-8986.3720127

Quamme, J. R., Yonelinas, A. P., & Norman, K. A. (2007). Effect of unitization on associative recognition in amnesia. *Hippocampus, 17*(3), 192–200. https://doi.org/10.1002/(ISSN)1098-106310.1002/hipo.v17:310.1002/hipo.20257

R Core Team. (2019). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. https://www.R-project.org/.

Regel, S., Gunter, T. C., & Friederici, A. D. (2011). Isn't It Ironic? An Electrophysiological Exploration of Figurative Language Processing. *Journal of Cognitive Neuroscience, 23*(2), 277–293.

Roediger, H. L., & McDermott, K. B. (1995). Creating False Memories: Remembering Words Not Presented in Lists. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*(4), 803–814.

RStudio Team. (2019). *RStudio: Integrated Development for R*. Boston, MA: RStudio Inc. http://www.rstudio.com/.

Sandra, D. (1990). On the Representation and Processing of Compound Words: Automatic Access to Constituent Morphemes Does Not Occur. *The Quarterly Journal of Experimental Psychology Section A, 42*(3), 529–567. https://doi.org/10.1080/14640749008401236

Sanquist, T. F., Rohrbauch, J. W., Syndulko, K., & Lindsley, D. B. (1980). Electrocortical Signs of Levels of Processing: Perceptual Anaysis and Recognition Memory. *Psychophysiology, 17*(6), 568–576.

Sassenhagen, J., Schlesewsky, M., & Bornkessel-Schlesewsky, I. (2014). The P600-as-P3 hypothesis revisited: Single-trial analyses reveal that the late EEG positivity following linguistically deviant material is reaction time aligned. *Brain and Language, 137*, 29–39. https://doi.org/10.1016/j.bandl.2014.07.010

Schulman, A. I. (1974). Memory for words recently classified. *Memory & Cognition, 2*(1A), 47–52. https://doi.org/10.3758/BF03197491

Staresina, B. P., Gray, J. C., & Davachi, L. (2009). Event Congruency Enhances Episodic Memory Encoding through Semantic Elaboration and Relational Binding. *Cerebral Cortex, 19*(5), 1198–1207. https://doi.org/10.1093/cercor/bhn165

Stites, M. C., Federmeier, K. D., & Christianson, K. (2016). Do morphemes matter when reading compound words with transposed letters? Evidence from eye-tracking and event-related potentials. *Language, Cognition and Neuroscience, 31*(10), 1299–1319. https://doi.org/10.1080/23273798.2016.1212082

Sutton, S., Braren, M., Zubin, J., & John, E. R. (1965). Evoked-Potential Correlates of Stimulus Uncertainty. *Science, 150*(3700), 1187–1188. https://doi.org/10.1126/science.150.3700.1187

Tibon, R., Cooper, E., & Greve, A. (2017). Does Semantic Congruency Accelerate Episodic Encoding, or Increase Semantic Elaboration? *The Journal of Neuroscience, 37*(19), 4861–4863. https://doi.org/10.1523/JNEUROSCI.0570-17.2017

Urbach, T. P., & Kutas, M. (2002). The intractability of scaling scalp distributions to infer neuroelectric sources. *Psychophysiology, 39*(6), 791–808. https://doi.org/10.1111/psyp.2002.39.issue-610.1111/1469-8986.3960791

Urbach, T. P., & Kutas, M. (2006). Interpreting event-related brain potential (ERP) distributions: Implications of baseline potentials and variability with application to amplitude normalization by vector scaling. *Biological Psychology, 72*(3), 333–343. https://doi.org/10.1016/j.biopsycho.2005.11.012

van Kesteren, M. T. R., Beul, S. F., Takashima, A., Henson, R. N., Ruiter, D. J., & Fernández, G. (2013). Differential roles for medial prefrontal and medial temporal cortices in schema-dependent encoding: From congruent to incongruent. *Neuropsychologia, 51*(12), 2352–2359. https://doi.org/10.1016/j.neuropsychologia.2013.05.027

van Kesteren, M. T. R., Fernandez, G., Norris, D. G., & Hermans, E. J. (2010). Persistent schema-dependent hippocampal-neocortical connectivity during memory encoding and postencoding rest in humans. *Proceedings of the National Academy of Sciences, 107*(16), 7550–7555. https://doi.org/10.1073/pnas.0914892107

Van Petten, C., & Luka, B. J. (2012). Prediction during language comprehension: Benefits, costs, and ERP components. *International Journal of Psychophysiology, 83*(2), 176–190. https://doi.org/10.1016/j.ijpsycho.2011.09.015

von Restorff, H. (1933). Über die Wirkung von Bereichsbildungen im Spurenfeld. *Psychologische Forschung, 18*(1), 299–342.

Wechsler, D. (1955). *Wechsler Adult Intelligence Scale*. New York: Psychological Corporation.

Wiegand, I., Bader, R., & Mecklinger, A. (2010). Multiple ways to the prior occurrence of an event: An electrophysiological dissociation of experimental and conceptually driven familiarity in recognition memory. *Brain Research, 1360*, 106–118. https://doi.org/10.1016/j.brainres.2010.08.089

Yagoubi, R. E., Chiarelli, V., Mondini, S., Perrone, G., Danieli, M., & Semenza, C. (2008). Neural correlates of Italian nominal compounds and potential impact of headedness effect: An ERP study. *Cognitive Neuropsychology, 25*(4), 559–581. https://doi.org/10.1080/02643290801900941

Zwitserlood, P. (1994). The role of semantic transparency in the processing and representation of Dutch compounds. *Language and Cognitive Processes, 9*(3), 341–368. https://doi.org/10.1080/01690969408402123