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Recognition memory for one-trial-unitized word pairs: Evidence from event-related potentials

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ABSTRACT

Performance in tests of associative memory is generally thought to require recollection while familiarity cannot support memory for associations. However, recent research suggested that familiarity contributes to associative memory when the to-be-associated stimuli are unitized during encoding. Here, we investigated the electrophysiological correlates of retrieval of word pairs after two different encoding conditions. Semantically unrelated word pairs were presented as separate lexical units in a sentence frame (non-unitized word pairs) or together with a definition that allows to combine word pairs to a new concept (unitized word pairs). At test, participants discriminated between word pairs that appeared in the same pairing during study, recombined, or new pairs. Memory processes were examined by means of event-related potentials (ERPs). An early old/new effect with a parietal maximum was found for unitized word pairs while a qualitatively different late old/new effect was elicited by non-unitized word pairs, only. These findings suggest that one-trial-unitized word pairs are recognized differently from non-unitized word pairs. We will discuss the possibility that unitization leads to the engagement of specific forms of familiarity—conceptual fluency and absolute familiarity.

Introduction

The human episodic memory system enables us to store and retrieve events or episodes that we have experienced before. As a part of that system recognition memory is the ability to realize that we have encountered an event before. Dual-process models propose two processes subserving recognition memory: recollection and familiarity. Recollection includes remembering contextual information about the learning episode (e.g., time and location of the encountering of a person). In contrast, familiarity refers to the feeling of knowing something or someone without the retrieval of additional information (for a review see Yonelinas, 2002).

While there is agreement that memory for single items can be supported by both processes, the contributions of recollection and familiarity to associative memory are unsettled so far. Associative recognition refers to the ability of recognizing that two or more items have previously occurred together. Associative memory tests require subjects to discriminate between old pairs (studied pairs) and recombined pairs (studied items in new combinations). As the single items of old and recombined pairs are equally familiar, it was argued that recollection is required to reactivate the newly built associations between arbitrary items (e.g., Yonelinas, 1997; Hockley and Consoli, 1999; Donaldson and Rugg, 1998). However, recent research suggested that familiarity contributes to associative memory when the to-be-associated stimuli are unitized during encoding (Yonelinas et al., 1999; Jäger et al., 2006; Rhodes and Donaldson, 2007, 2008; Quamme et al., 2007). In the current study, we set out to further explore the circumstances under which familiarity contributes to associative memory.

In recent years, dual-process models gained substantial support as the two processes could be functionally and neuroanatomically dissociated by several neuroimaging (Eldridge et al., 2000; Henson et al., 2003; Ranganath et al., 2003) and neuropsychological case studies (Düzel et al., 2001; Bowles et al., 2007). Others, however, have argued that data from the recognition memory paradigm can be explained by assuming only a single continuum of memory strength (usually within the context of signal detection theory; Dunn, 2004; Heathcote, 2003). Under such a notion, the sense of familiarity only reflects a weaker trace strength than recollection of prior information, i.e., these two processes differ only quantitatively (see Squire et al., 2007, for a review). However, dual process models are also favored because a variety of event-related potential (ERP) studies have shown that familiarity and recollection are related to two qualitatively distinct event-related brain potentials (ERPs). Familiarity was associated with an early mid-frontal old/new effect between 300 and 500 ms while recollection was related to a parietal old/new effect

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between 400 and 800 ms (Rugg et al., 1998; Curran, 2000; Jäger et al., 2006; Mecklinger, 2000; Woodruff et al., 2006; however, the exact functional meaning of the early mid-frontal old/new effect is still under debate and it has also been associated with conceptual priming, e.g., Voss and Paller, 2006, 2007; Paller et al., 2007).

As outlined above, there is still debate whether both processes, recollection and familiarity, support associative recognition memory. The view that associative recognition memory requires recollection receives support from a number of studies testing recognition of arbitrary pairs (e.g., Yonelinas, 1997; Hockley and Consoli, 1999; Donaldson and Rugg, 1998). However, the latter notion is challenged by recent studies (Yonelinas et al., 1999; Jäger et al., 2006; Rhodes and Donaldson, 2007, 2008; Quamme et al., 2007; Haskins et al., 2008) showing that recognition memory for associations can be based on familiarity if the to-be-associated information is encoded as a single configuration and forms a unitized representation (like a face is perceived as a whole and not as several single parts). Unitized information is perceived and processed like a single item (e.g., Hayes-Roth, 1977; Mandler, 1962). Therefore, unitized pairs can be familiar as a whole and recollection of the link between the two items is not necessary for successful recognition. Conversely, according to the domain dichotomy view proposed by Mayes et al. (2007), familiarity is engaged for the retrieval of associated items only when the representations of the items in the pair are overlapping, i.e., when the to-be-associated items share a sufficient amount of common features.

Up to now, the influence of unitization on memory retrieval processes has been investigated using different methodological approaches. Yonelinas et al. (1999) used Receiver Operating Characteristic (ROC) curves to investigate unitization of face parts. They found a larger contribution of familiarity to recognition memory when the faces were presented upright and, in turn, could be holistically processed, as compared to an upside-down condition, in which the faces were presumably processed as a collection of separable features. This suggests that associations between well-integratable features could be automatically activated and in turn increase the extent to which associative recognition is supported by familiarity. In a more recent ROC study, unitization was induced using mental imagery instructions, i.e., an object had to be imagined in the background color (i.e. the source). This instruction significantly increased the familiarity estimate derived from the ROC curves relative to a control condition in which item and source information were not unitized during encoding (Diana et al., 2008). Notably, inferences on familiarity and recollection drawn from ROC analyses need to be treated with some caution as the conclusions critically depend on whether single or dual process models are applied to fit the data (Yonelinas, 2002).

An interesting attempt to test the unitization hypothesis was recently pursued by Quamme et al. (2007) who examined the impact of encoding processing on associative recognition memory for unrelated word pairs. This approach has the advantage that pre-experimental relationships between words can be controlled for and an entity defining framework is established by means of encoding instructions. Participants either learned word pairs together with a definition combining the two words to a new concept (unitized) or studied word pairs as separate lexical items within a sentence frame (non-unitized). Amnesic patients, who had previously demonstrated impaired recollection and spared familiarity, showed enhanced performance in the definition condition while performance in the sentence condition seemed to be only marginally above chance level. These findings can be taken as preliminary evidence that familiarity can support associative recognition memory when two arbitrary words are combined to a new concept. However, the results should also be interpreted with some caution as the actual extent of the lesions was not confirmed by magnetic resonance tomography due to medical reasons and only five amnesic patients were tested.

Another source of evidence for the view that familiarity can support retrieval in an associative recognition task comes from recent ERP studies. Most of these studies used pre-experimentally conceptually integrated items. Opitz and Cornell (2006) asked subjects to memorize four words in each study trial. In two encoding conditions, participants indicated which word did not fit in the associative context of the other words (e.g., *oasis, camel, chair, desert*; associative condition) or indicated which of the four words denoted the smallest object word (relational condition). Consistent with the authors' prediction that only the associative condition should promote the activation of pre-existing conceptual relationships between the words, a mid-frontal old/new effect was only obtained when words from the associative condition were retrieved.

Testing associative recognition directly, Greve et al. (2007) presented word pairs that were either preceded by the compatible category name (*animal: rabbit–mouse;* semantic condition) or an incompatible category name (*plant: ball–radio;* non-semantic condition) in an associative memory test. Associative recognition for the word pairs was significantly enhanced for semantically coherent materials. A mid-frontal old/new effect was larger for the semantically coherent word pairs whereas no differences were found for the parietal old/new effect between both conditions. These findings implicate that the activation of semantically coherent information facilitates familiarity-based recognition. Using a similar paradigm, Rhodes and Donaldson (2007) compared associative memory for word pairs that belonged to either of three categories: pre-experimentally associated but not semantically related (*traffic–jam*), semantically related and associated (*lemon–orange*), or semantically related but not associated (*violin–guitar*) word pairs. For associated word pairs only, a mid-frontal old/new effect was found. This finding is interpreted as support for pre-existing unitized representations that are based on the associative relationship between the two words and that also allow familiarity-based remembering.

A recent study by Rhodes and Donaldson (2008) suggests that whether or not associative recognition is supported by familiarity depends not only on the properties of the to-be-remembered word pairs but also on task demands. Examining associative recognition for associated word pairs and semantically related word pairs, they found a mid-frontal old/new effect for semantically related pairs in a condition that encourages unitization (i.e. interactive imagery) but not in an item imagery condition. For associated word pairs, the mid-frontal old/new effect was obtained in both conditions. Semantically related and associated word pairs evoked a parietal old/new effect that was not modulated by encoding instruction. These results demonstrate that task instructions at encoding can lead to the engagement of familiarity at retrieval. However, as conceptually related word pairs were used, it cannot be excluded that pre-experimental conceptual knowledge has contributed to familiarity-based recognition.

In the current study, we further explored the circumstances under which familiarity contributes to associative memory. The aforementioned studies suggest that the properties of the information to be memorized (as for example pre-experimental knowledge) as well as the task demands at encoding can modulate the contribution of familiarity and recollection to associative recognition memory. Expanding upon the finding from Rhodes and Donaldson (2008), two issues were explored: First, we were interested in whether familiarity is engaged in addition to recollection at retrieval when completely arbitrary and pre-experimentally unrelated word pairs have to be remembered. Second, we examined whether this effect can be obtained by using another technique than interactive imagery to encourage unitization at encoding.

Using a between-subjects design, semantically unrelated German word pairs were presented once as either separate lexical units in sentence frames (sentence condition) or along with a definition combining the two words to a new concept (definition condition).

We used an incidental memory paradigm to avoid any other encoding strategies which could reduce the discriminability between the two study tasks. At test, participants were required to discriminate between old word pairs that appeared in the same pairing as at study, recombined word pairs (pairs of words that appeared in different pairings at study) or completely new pairs. Although not standard in behavioral studies, new pairs were included in order to obtain ERP old/new effects which are comparable to the standard item old/new effects (see Fig. 1 for the time course of the study and test phases).

On the basis of the aforementioned results, which showed that familiarity can support the recognition of unitized word pairs, we expected familiarity to support recognition of the to-be-associated word pairs in the definition but not in the sentence condition. This should be reflected in an enhanced early mid-frontal old/new effect between old and new word pairs in the definition condition. As memory for study details is assumed irrespective of encoding instructions, recollection is expected to support recognition memory in both conditions. This should be expressed in a late parietal old/new effect between old and new word pairs.

Experimental procedures

Participants

A total of 48 students from Saarland University participated in this experiment. Data from eight subjects had to be excluded due to (a) an insufficient number (< 12) of artifact free trials in the three response categories (2), (b) too low discrimination performance between old and recombined pairs (1), (c) too low discrimination performance between recombined and new pairs (4), and (d) too many time-outs (1). The mean age of the remaining 20 participants (12 female) in the definition condition was 23.65 years (range 19–27) and 23.80 years (range 21–29) for the remaining 20 participants (11 female) in the sentence condition. All participants were right-handed as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971) and had no known neurological problems. Informed consent was required, payment was provided at a rate of €8/h, and participants were debriefed after the experiment. The experiment was approved by the local ethics committee of Saarland University.

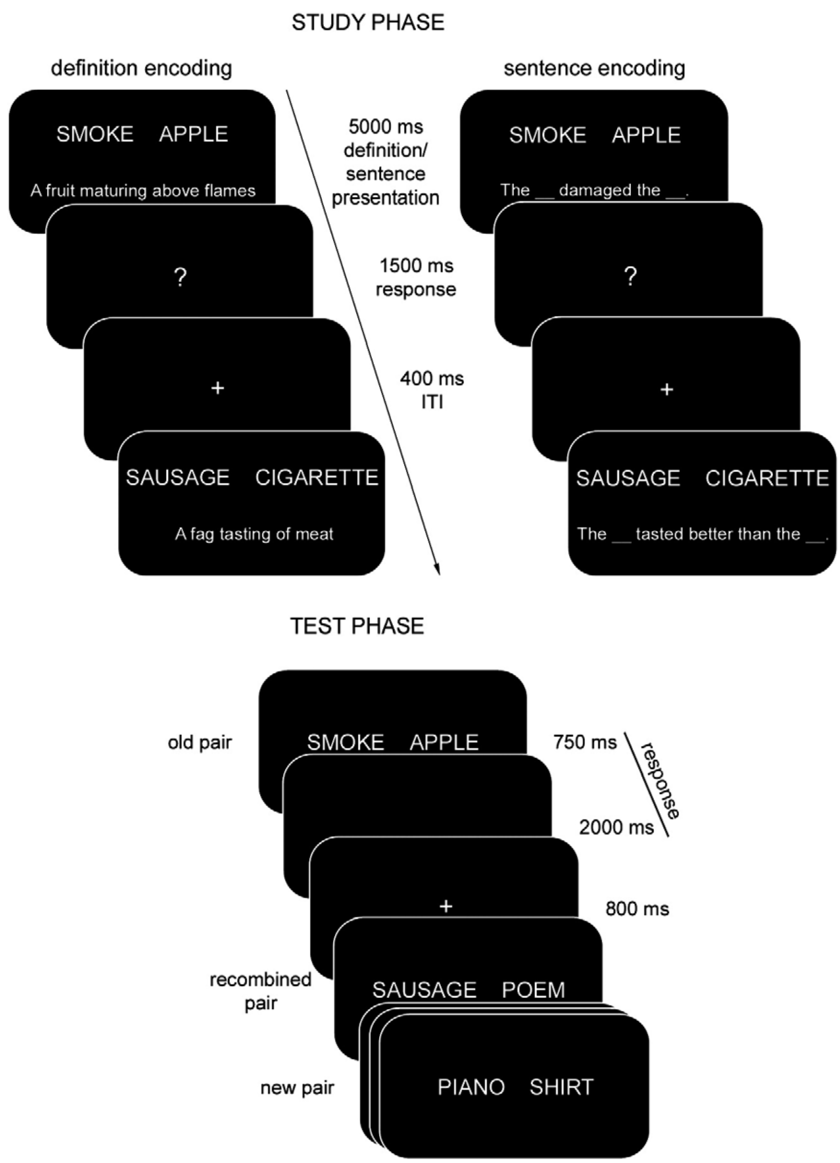

Fig. 1. Time course of events in the study and test phase. In the definition trials, participants were instructed to imagine the new concept and then to rate how well the definition denoted the new concept. In the sentence condition, participants were instructed to rate how well the two words fit in the sentence frame. Responses had to be made during the response interval after the stimulus presentation. In the test phase, participants had to discriminate between word pairs which they had encountered during the study phase (old), pairs consisting of familiar words but in new combinations (recombined) and totally new pairs.

Stimuli

Study stimuli comprised 96 unrelated word pairs including the corresponding definitions and sentences which had been selected by means of a rating study. For this purpose, 128 arbitrary German word pairs were chosen from the CELEX database (Baayen et al., 1993). The single items were singular nouns of moderate frequency (10–500 occurrences per million). Extremely low and high frequent words were omitted as familiarity and recollection for words can be influenced by their frequency (e.g., Rugg et al., 1995; Arndt and Reder, 2002). Word length was restricted to 4–10 letters. Pairings were constituted under the constraints of unrelatedness and suitability to build a compound together without the need for any alternations (e.g., omission of the first word's final –e, an additional –n or –s to link the words in German). A definition combined each word pair to a new concept. Definitions consisted of a noun phrase followed by a relative clause containing at least 5 but no more than 10 words. Only synonyms or associates of the actual items were used in the definitions. Repetition of the words was avoided to enhance the comparability of the definition and the sentence condition as in the sentence condition the words in the sentences were substituted by blank spaces. Sentences contained the two words of a pair in the same order as in the pair.

The three parts of the pilot rating study were supposed to assure that one of the following three constraints were met, respectively. First, the two words of one pair had to be semantically unrelated in order to minimize the probability of pre-experimental associations. Second, definitions had to be rated as providing a good description combining the two words to a new concept in order to facilitate unitization. Third, the sentences should be considered to be plausible to avoid any specific memory effects related to plausibility. One hundred seventy-seven psychology students completed one of the three parts, i.e., for each pair, they either had to rate on a 4-point-scale how strongly the two words were semantically related, how well the combination of the two words denoted the new concept, or how well the two words fitted into the sentence. Out of the 128 pairs presented in the rating study, 96 pairs were chosen due to the highest scores in the definition rating. These pairs also met the requirement of not being rated as related and the corresponding sentences were not rated as 'very implausible'.

The test phase comprised three kinds of word pairs: 48 old pairs, which had already been presented in the study phase, 48 totally new pairs, of which both words had not been seen before, and 48 recombined pairs, which were new combinations of words presented in the study phase together with another partner. These latter pairs were included to prevent subjects from differentiating between old and new pairs on the basis of pure item recognition. Building the recombined pairs for the test phase, the study pairs were divided into two item groups. Within these item groups, the single words were recombined. Each single word from the study phase reappeared in the test phase. Position of words (first or second within a pair) was maintained. To equate the semantic relatedness between all three types of word pairs, the unrelatedness of recombined and new pairs was evaluated in a second rating study, in which 57 participants were asked to judge the semantic relation of the recombined and new pairs. One of the recombined pairs had to be excluded due to being rated as rather related resulting in a reduced number of only 47 recombined pairs in one of the item groups.

Two test lists were constructed in the following manner. List 1 contained old pairs out of item group 1 and recombined pairs out of item group 2 and vice versa for list 2. The same set of 48 new pairs was added to both lists. The order of pairs in the two lists was pseudo-randomized. The same type of pair was not presented more than three times consecutively and two recombined pairs containing words of the same old pair were not presented successively. Both test lists were divided into two blocks resulting in 24 old pairs, 24 new pairs, and 24 recombined pairs (23 recombined pairs in one block of item group 2) in each block.

Design and procedure

The experiment was designed using E-Prime (Psychology Software Tools). It was conducted on a standard PC with a Vision Master Pro 451 Ilyama 19 in.-monitor. Participants were sat in front of the monitor in a viewing distance of approximately 80 cm. All stimuli were displayed in white against a black background. In the study phase, word pairs were presented next to each other, separated by four blanks. Definitions and sentences were displayed in Arial 16 point font. Word pairs and definitions or sentences, respectively, were displayed one above the other, slightly above and below central vision. Sentence frames used in the sentence condition were constructed with two blank spaces, where the first item was intended to fit into the first space, and the second item was intended to fit into the second space. In the test phase, word pairs were presented next to each other in central vision, separated by four blanks.

To prevent a spill over of encoding strategies, encoding condition was manipulated between subjects. Participants in the definition condition were instructed to rate the pair as a whole on a scale from 1 ('very badly') to 4 ('very well') according to how well the definition combined the meanings of the two words into a sensible compound. To do so, they were told to consider how good their imagination of the new concept was. In the sentence condition, participants were instructed to rate how well the two words fitted into the sentence frame and how plausible the whole sentence was. In both encoding conditions, presentation duration of the stimuli was 5000 ms, followed by a 50 ms blank screen and a response window of 1500 ms indicated by a question mark in the center of the screen. Participants responded via the keys 'x', 'c', 'n' and 'm' of a keyboard using their middle and index fingers of both hands. The 96 study pairs were presented in random order. After 48 trials, there was a self-paced break.

After the study phase, there was a 5-min-retention interval, in which subjects had to perform a distracter task (they had to detect a specific combination in a series of characters). Thereafter, participants were informed about the upcoming test phase.

In the test phase, participants were instructed to decide whether the presented word pair was old, new, or recombined. Responses were made via the same keys as in the study phase. Mapping of responses and keys was varied across subjects. In both encoding groups, half of the subjects responded 'old' using the left middle finger and 'new' using the right middle finger. Half of these subjects made a 'recombined'-response using the right index finger, the other half made it using the left index finger. The remaining 50% responded 'old' using the right middle finger and 'new' using the left middle finger. Again, half of these subjects used the right index finger for the 'recombined'-response and the other half used the left index finger. Word pairs were displayed for 750 ms followed by a 2000 ms blank screen. The response window began at stimulus onset and ended with offset of the blank screen. The 144 test trials were presented in two blocks interrupted by a self-paced break. In both encoding conditions, order of blocks and item group was completely counterbalanced.

Data acquisition and processing

Electroencephalograms (EEGs) in the test phase were continuously recorded from 61 Ag/AgCl scalp electrodes mounted in an elastic cap and labeled according to the extended 10–20 system (Sharbrough et al., 1991). All electrodes were recorded with reference to the left mastoid electrode. Data were re-referenced offline to the average of the left and right mastoid. Additional electrodes were located above and below the right eye and outside the outer canthi of both eyes in order to assess electroocular activity. All channels were amplified with a band pass from DC to 70 Hz and digitalized at a rate of 500 Hz. Electrode impedances were kept below 10 kΩ. Data was recorded with the BrainVision Recorder V1.02 (Brain Products). Offline data

Table 1
Mean percentage of correct responses and mean reaction times for the three item types (standard error of the mean). Note that the data for recombined pairs did not enter the statistical analyses.

		Item type		
		old	new	recombined
% Correct	definition	71 (3)	69 (2)	63 (3)
	sentence	71 (2)	70 (2)	58 (3)
Reaction times (ms)	definition	1464 (46)	1610 (51)	1682 (49)
	sentence	1532 (60)	1549 (57)	1779 (62)

processing was performed with EEProbe (ANT Software). It comprised a digital band-pass filter set to 0.5 and 30 Hz, respectively. After forming individual epochs of 1500 ms (including a 300 ms baseline), eye-movements were corrected using a linear regression algorithm, and epochs including other recording artifacts were rejected before averaging. Proportion of trials rejected were 16% (old), 14% (recombined), and 17% (new) in the definition condition and 16% (old), 14% (recombined), and 18% (new) in the sentence condition. Mean number of analyzed trials were 28.1 (old), 26.1 (recombined), and 27.6 (new) in the definition condition and 28.0 (old), 22.8 (recombined), and 27.5 (new) in the sentence condition. Analysis was performed on mean voltage data relative to the pre-stimulus baseline period. For illustration purposes, a 12 Hz low pass filter was applied.

Data analyses

For inferential statistics multivariate analyses of variance (MANOVAs) were conducted as recommended by Dien and Santuzzi (2005). Subsidiary analyses were performed using MANOVAs or *t*-tests as appropriate. Probability values (*p*-values) for follow-up analyses were adjusted applying Holm's sequential Bonferroni correction (Holm, 1979). The significance level was set to $\alpha = .05$. For all analyses, only correct responses were analyzed.

Recombined responses were not included in the analyses as interpretation of the results concerning recombined pairs is difficult. Each single item which appeared in the study phase of the experiment reappeared in the test phase. Therefore, processing of a recombined pair could suffer from interference by the prior occurrence of the study phase partner(s) in the test phase. This aspect contaminates the comparability of recombined and old pairs. This interference problem is evident in the low accuracy and long response times for recombined pairs (see Table 1). Additionally, as accuracy for recombined pairs was lower than for the other two item types, the signal-to-noise ratio for the ERPs to these pairs was relatively low.

MANOVAs for the behavioral data included the between-subjects factor Encoding Condition (definition, sentence) and the within-subjects factor Item Type (old, new). ERP data included mean amplitudes in the respective time windows from three frontal (F3, Fz, F4), three central (C3, Cz, C4), and three parietal (P3, Pz, P4) electrodes. An initial higher level MANOVA included the between-subjects factor Encoding Condition (definition, sentence) and the within-subjects factors Item Type (old, new), Location (frontal, central, parietal), Laterality (left, midline, right) and Time Window (early, late). Follow-up analyses were restricted to specific time windows and encoding conditions. Only main effects and interactions including the factor Item Type are reported.

Results

Behavioral data

Mean response frequencies for the three types of pairs are illustrated in Table 1. A MANOVA with the within-subjects factor Item Type (old, new) and the between-subjects factor Encoding Condition (definition, sentence) revealed neither a significant main effect of Item Type or Encoding Condition [*F*-values<1] nor a significant interaction [$F<1$]. Notably, there were no differences in recognition accuracy between the encoding conditions.

Mean reaction times for the three response categories are shown in Table 1. A MANOVA with the between-subjects factor Encoding Condition (definition, sentence) and the within-subjects factor Item Type (old, new) revealed a main effect of Item Type [$F(1,38) = 13.19$, $p < .01$] and a significant Item Type by Encoding Condition interaction [$F(1,38) = 8.23$, $p < .01$], but no main effect of Encoding Condition. Dissolving the interaction, in the definition encoding group, old responses were faster than new responses [$t(19) = 4.14$, $p < .01$], whereas in the sentence encoding group, there was no difference between correct old and new responses. Furthermore, separate analysis for old responses and new responses did not reveal any group differences (*t*-values<1). As for the accuracy data, there were no overall group differences between the encoding conditions.

Electrophysiological data

ERPs at midline frontal, central and parietal recording sites elicited by correct old and new responses in the two encoding conditions are shown in Fig. 2. In both conditions, new pairs elicit a pronounced negativity with a central maximum that peaked at around 400 ms. The ERP waveforms to old stimuli start becoming more positive than those to new stimuli at about 350 ms after stimulus onset. In contrast to the definition condition, ERPs to old stimuli in the sentence condition diverge from ERPs to new stimuli also in a later time window from 500 ms on. Consistent with previous studies and visual inspection of the grand average waveforms, the ERP data were analyzed in two time windows of 350–500 ms (early) and 500–700 ms (late) related to the early mid-frontal and late parietal effect, respectively.

The topographical distribution of the difference between old and new ERPs is shown in Fig. 3. The early old/new effect in the definition condition is maximal over parietal sites whereas the late effect in the sentence condition is most pronounced over central sites.

Old/new effects—Overall analysis

The five-way MANOVA with the between-subjects factor Encoding Condition (definition, sentence) and the within-subjects factors Item Type (old, new), Location (frontal, central, parietal), Laterality (left, midline, right), and Time Window (early, late) revealed a significant effect of Item Type [$F(1,38) = 14.69$, $p < .001$], a significant two-way interaction of Item Type and Laterality [$(2,37) = 3.36$, $p < .05$], significant three-way interactions of Item Type, Location, and Time Window [$F(2,37) = 3.30$, $p < .05$] and Item Type, Location, and Laterality [$F(4,35) = 3.36$, $p < .05$], a marginal significant three-way interaction of Item Type, Time Window, and Encoding Condition [$F(1,38) = 3.77$, $p < .06$], and a four-way interaction of Item Type, Time Window, Laterality, and Encoding Condition [$F(2,37) = 7.61$, $p < .01$]. In the following, the latter interactions will be dissolved by analyzing old/new effects separately for both time windows.

Early time window (350–500 ms)

A MANOVA with the factors Encoding Condition, Item Type, Location, and Laterality revealed a significant effect of Item Type [$F(1,38) = 11.04$, $p < .01$], a marginal significant two-way interaction of Item Type and Laterality [$F(2,37) = 3.14$, $p < .06$], and a significant three-way interaction of Item Type, Location, and Laterality [$F(4,35) = 3.38$, $p < .05$]. The interaction of Item Type and Encoding Condition did not reach significance [$F<1$]. Dissolving the interactions involving the factors of Location and Laterality, separate Encoding Condition by Item Type MANOVAs were calculated for each electrode site yielding significant effects of Item Type for

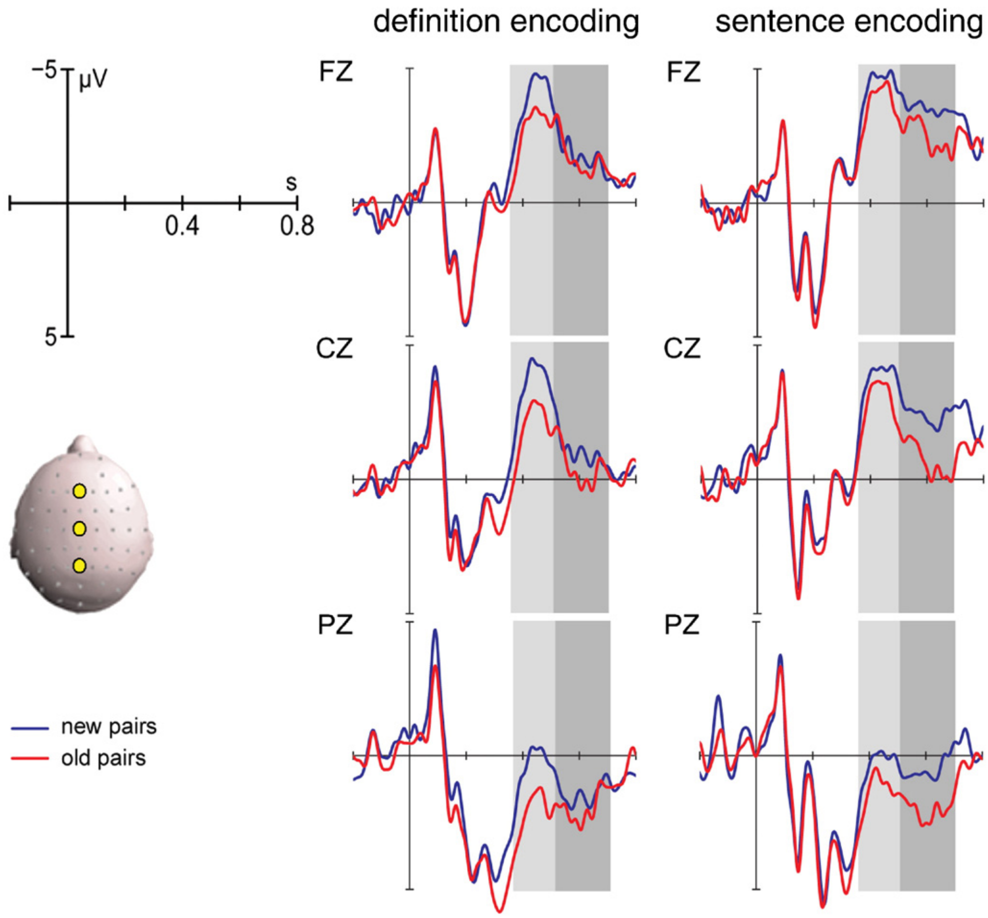

Fig. 2. ERP waveforms for old and new responses at electrodes Fz, Cz, and Pz during the 350–500 ms time window (light bars) and the 500–700 ms time window (darker bars) in the definition condition and the sentence condition.

electrodes Pz ($p<.01$), P4 ($p<.01$), C4 ($p<.05$), Cz ($p<.05$), F4 ($p<.05$), and F3 ($p<.05$). The interaction of Item Type and Encoding Condition was not significant at any of the electrode sites (p-values>.28).

Although the interaction of Item Type and Encoding Condition was not significant, separate MANOVAs for each condition were conducted licensed by the specific hypotheses about the presence and absence of the early effects in the two conditions. For the definition condition, a MANOVA with the factors Item Type, Location, and Laterality revealed an effect of Item Type [$F(1,19)=8.42$, $p<.01$] and a significant three-way interaction [$F(4,16)=3.44$, $p<.05$]. Follow-up analyses yielded significant old/new differences for electrodes Pz ($p<.05$), P4 ($p<.05$), and Cz ($p<.05$). For the sentence condition, the corresponding analysis revealed marginally non-significant effects of Item Type [$F(1,19)=3.35$, $p<.09$] and of Item Type by Laterality [$F(2,18)=2.79$, $p<.09$]. In sum, the analyses for the early time interval revealed a reliable and topographically wide

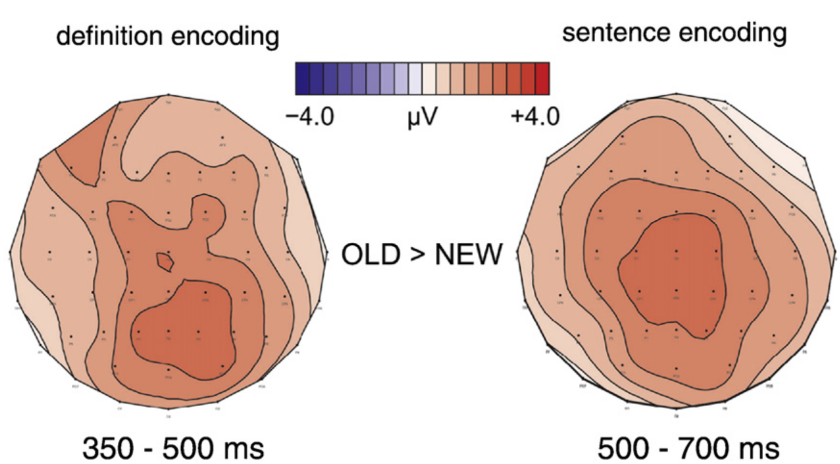

Fig. 3. Topographic maps showing the pattern of old minus new differences across the scalp during the 350–500 ms time window for the definition condition and during the 500–700 ms time window for the sentence condition.

spread old/new effect which exhibited a parietal maximum in the definition condition and was substantially smaller and did not reach the significance level in the sentence condition.

Late time window (500–700 ms)

A MANOVA with the factors Encoding Condition, Item Type, Location, and Laterality revealed a significant effect of Item Type [$F(1,38) = 7.97$, $p < .01$], a significant two-way interaction of Item Type and Laterality [$F(2,37) = 3.78$, $p < .05$], marginal significant two-way interactions of Item Type and Location [$F(2,37) = 2.96$, $p < .07$] and of Item Type and Encoding Condition [$F(1,38) = 2.89$, $p < .10$], and a significant three-way interaction of Item Type, Location, and Laterality [$F(4,35) = 3.12$, $p < .05$]. In order to dissolve the interactions involving the factors Location and Laterality, separate MANOVAs with the factors Item Type and Encoding Condition were performed for each electrode site. Significant effects of Item Type were obtained for electrodes Cz ($p < .05$), Pz ($p < .05$), and P4 ($p < .05$). The interaction of Item Type and Encoding Condition was not significant at any of the electrodes (p-values > .18). Again, although the interaction of Item Type and Encoding Condition failed to reach significance, we performed separate MANOVAs for each condition to test our hypotheses. For the definition condition, the three-way MANOVA revealed neither a significant main effect of Item Type [$F < 1$] nor any interactions [F-values < 2.22] whereas in the sentence condition an effect of Item Type [$F(1,19) = 8.17$, $p < .05$] and interactions of Item Type and Location [$F(2,18) = 3.92$, $p < .05$] and of Item Type and Laterality [$F(2,18) = 6.62$, $p < .01$] were obtained. Follow-up analyses revealed significant old/new differences for electrodes C3 ($p < .01$), Cz ($p < .01$), F3 ($p < .05$), and Pz ($p < .05$). These analyses suggest that there is a broadly distributed late old/new effect which is most pronounced at middle and left central sites and only of significance in the sentence condition.

Comparison of early and late old/new effects

The differential modulation of the early and late old/new effects by encoding condition is illustrated in Fig. 4 which shows the old minus new difference scores for the early and late old/new effects at the mid parietal (early) and mid central (late) recording sites. The early effect was present in the definition condition (and marginally non-significant in the sentence condition) and the late effect was only obtained in the sentence condition. The statistical reliability of this differential modulation of the two effects was assessed by a MANOVA with the factors Effect (early effect at Pz, late effect at Cz) and Encoding Condition (definition, sentence). There was neither a main effect of Effect nor of Encoding Condition [F-values < 1], but a significant interaction of Effect and Encoding Condition [$F(1,38) = 5.67$, $p < .05$]. This latter interaction confirms that the processes underlying the two effects indeed play differential roles in the two different encoding conditions.

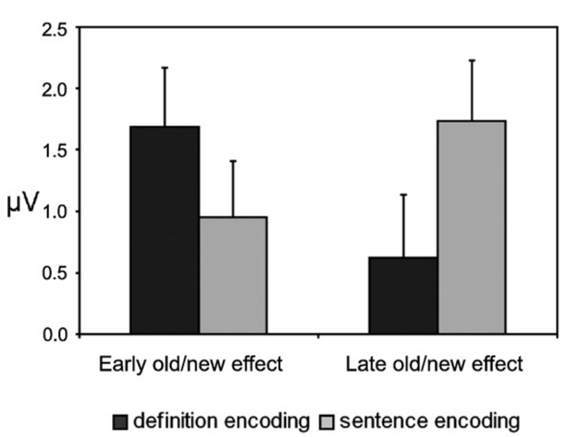

Fig. 4. Mean magnitude of the old/new effects in both encoding conditions at electrode Pz in the early time window (350–500 ms) and at electrode Cz in the late time window (500–700 ms). Error bars represent the standard error of the mean.

Topographic analyses

To examine whether qualitatively different configurations of neural generators unconfounded by overall amplitude underlie the two effects, topographical analyses were performed on the old/new difference scores using rescaled data (McCarthy and Wood, 1985; Wilding, 2006). A MANOVA with the factors Encoding Condition/Time Window (definition early, sentence late), Location (frontal, central, parietal), and Laterality (left, midline, right) yielded an interaction of Encoding Condition/Time Window and Location [$F(2,37) = 5.206$, $p < .05$] indicating that both old/new effects differ in their configurations of underlying neural generators.

Discussion

In the present study, we compared ERP correlates of the retrieval of semantically unrelated word pairs after two different encoding conditions which were intended to encourage or discourage unitized encoding. In the definition condition, word pairs were presented together with a definition combining the two words to a new concept. Conversely, in the sentence condition, the same word pairs were presented together with a sentence frame in which the two words had to be processed as separate lexical items. We assumed that providing an entity defining framework should foster holistic processing resulting in one unitized representation instead of two associated representations. In contrast, no such unitization process was expected to take place in the sentence condition. Consistent with previous studies, we expected the two encoding conditions to lead to a difference in the relative contribution of familiarity and recollection in the subsequent test phase. Word pairs in the definition condition were expected to be recognized on the basis of familiarity and in turn should elicit a mid-frontal old/new effect, the putative ERP correlate of familiarity, whereas recognition of non-unitized word pairs in the sentence condition was expected to rely to a major extent on recollection being reflected in the late parietal old/new effect, the putative ERP correlate of recollection.

Across conditions, we found an early old/new effect in the time window from 350 to 500 ms with an unusual and not expected broad topographical distribution. This effect was statistically reliable in the definition condition (partial $\eta^2 = .31$, Tabachnik and Fidell, 2007) exhibiting a maximum over parietal electrode sites. In the sentence condition, there was a marginally non-significant old/new effect in this time window (partial $\eta^2 = .15$).

In the later time window from 500 to 700 ms, an old/new effect with a centro-parietal maximum was observed. This late parietal old/new effect was significant only in the sentence condition (partial $\eta^2 = .30$) and not in the definition condition (partial $\eta^2 = .04$). Crucially, the two conditions differ in their relative contribution of the processes underlying the early and late old/new effect which was confirmed by an analysis which compared the early and late effect at the electrodes where the effects were found to be maximal (Pz and Cz, respectively). Moreover, topographic analyses revealed that qualitatively different configurations of underlying neural generators are associated with the two effects—suggesting two different processes being involved. Below, the functional significance of the effects will be discussed in turn.

Importantly, analyses of recognition accuracy revealed no major differences between the two encoding conditions ensuring that ERP differences between both groups were not confounded by differences in recognition memory performance. A difference between groups was revealed for reaction times. In the definition condition, old responses were faster than new responses. Conversely, no such difference was found in the sentence condition. This suggests that definition encoding leads to faster retrieval of old items.

The late parietal old/new effect

Although the late old/new effect in the present study was rather broadly distributed and had no clear parietal maximum, it can be assumed that it reflects recollection as this is a well-approved finding in ERP studies on associative memory and the old/new effect in the sentence condition was statistically reliable at parietal sites, at which the late parietal old/new effect in associative memory studies is commonly observed (Donaldson and Rugg, 1998; Mecklinger and Jäger, 2009). The late parietal old/new effect was found in the sentence condition replicating various findings from ERP associative memory studies (e.g., Donaldson and Rugg, 1998; Rhodes and Donaldson, 2007). In contrast, in this late time window, no significant difference between ERPs to old and new pairs was found in the definition condition suggesting that performance does not rely on recollection if the words are processed as a single configuration (Jäger et al., 2006). This finding is in contrast to prior ERP studies contrasting encoding conditions that either encourage or discourage unitization of word pairs. It is conceivable that the present unitization instruction differed from the interactive imagery instruction used by Rhodes and Donaldson (2008), especially as it was an incidental memory paradigm. Due to an efficient unitization mechanism successful recognition is possible on the basis of some sort of familiarity alone (see discussion below) and recollection is not required for remembering the new concept. It could be argued that there are numerous elements of the study event that might be recollected at test for pairings from the definition condition. However, recollection was not explicitly fostered by the task instructions in the test phase. So, only some subjects may have engaged recollective processing and others may have not (Sugiura et al., 2007) and this inter-subject variability may have resulted in the absence of the parietal old/new effect in the definition encoding condition. Conversely, if the two words are not unitized as it was the case in the sentence encoding condition, only the separate lexical items can be familiar but not the pair as a whole and recollection is definitely required to retrieve the word pairs. The present data are consistent with this view.

The early old/new effect

As outlined above, the early old/new effect did not exhibit the expected mid-frontal distribution which makes the interpretation of this effect as reflecting familiarity less straightforward. Most studies report a maximum of this effect at frontal or fronto-central electrodes (e.g., Curran, 2000; Nessler et al., 2005; Opitz and Cornell, 2006) but rather broad distributions are less frequently reported. For example, a topographical shift to central recording sites was observed by Mecklinger (2006), who examined recognition memory for visually presented real-world objects. Also, Düzel et al. (1997) reported a tempero-parietal pronounced old/new effect around 400 ms to previously seen words associated with the subjective experience of “knowing”, a cognitive state thought to reflect familiarity.

On the basis of its posterior topographic distribution, one could argue that the early parietal old/new effect in the definition condition is nothing more than an earlier onsetting version of the late parietal old/new effect obtained in the sentence condition. However, this possibility can be ruled out as the topographical analyses have shown that the early and late effect in the present study differ in the configuration of their underlying neural generators strongly suggesting two qualitatively different underlying processes.

The early old/new effect might also be seen as an instantiation of conceptual priming—the facilitation of behavior due to prior access to related meaning (Voss and Paller, 2006, 2007; Paller et al., 2007). Paller et al. argue that in most studies, measures of explicit memory processes are contaminated by influences of implicit memory mechanisms and if those priming mechanisms are taken into account in explicit memory tasks, the early old/new effect is associated with conceptual priming rather than familiarity. However, the ERP effect associated with conceptual priming in the studies of Voss and Paller (2006, 2007) consistently displayed a frontal topographical distribution. This makes an interpretation of the early parietally focused effect in the definition condition in terms of conceptual priming rather unlikely.

Nevertheless, the question remains, why we did not find the standard mid-frontal effect. The topography of our early old/new effect resembles closely the one of the so-called N400 component which is reduced when semantic integration is facilitated by contextual information (Kutas and Federmeier, 2000). Although N400 modulations at test are commonly found to be independent of correct recognition (Olichney et al., 2000; Wolk et al., 2004), Wolk et al. proposed that the ease of semantic integration could be used to make recognition judgments, however, only when this experience of conceptual fluency is attributed to a prior study event (e.g., Whittlesea and Williams, 2001). The integration of the pre-experimentally unrelated word pairs to a new concept in the present study may have facilitated conceptual processing of the word pairs in the test phase and attenuated the N400. In contrast, processing of new pairs in the test phase was more effortful as they were not integrated. Moreover, subjects expected old pairs to be more conceptual fluent than new pairs as they have learned the meaning of the newly build concepts during the study phase. Therefore, they might have attributed the greater conceptual fluency of the old pairs to the study experience and used this signal to judge them as old (Whittlesea and Williams, 2001). The shorter reaction times for old relative to new responses in the definition condition are consistent with the view that definition encoding has enhanced conceptual fluency in the test phase. Relating the early old/new effect in this study to conceptual fluency is reasonable as many conceptual features might have been activated by the instruction to combine the two words to a new concept during the study phase. The key point here is that these very specific task conditions might have led participants to rely on conceptual fluency to make their response as it was a reliable diagnostic means. This distinguishes the present task from the majority of recognition memory tasks.

Interestingly, a parietal maximum of the early old/new effect related to familiarity was found in studies using pre-experimentally unfamiliar stimuli, as for example faces of unknown individuals or novel figures (MacKenzie and Donaldson, 2007; de Chastelaine et al., 2009; but see Yovel and Paller, 2004; Nessler et al., 2005). MacKenzie and Donaldson (2007) suggest that for tasks in which previously unencountered and novel stimuli are used, the assessment of their absolute familiarity is more diagnostic than the assessment of relative familiarity whereas in tasks with pre-experimentally familiar stimuli only relative familiarity is informative (e.g., old words in a recognition test are relatively more familiar than new words but both kinds of words are absolute familiar). This notion is in line with Mandler's (1980) distinction between incremental and baseline familiarity. Baseline familiarity or absolute familiarity refers to a given strength of the memory representation whereas incremental or relative familiarity refers to the increase of the familiarity signal relative to the pre-experimental baseline. Support for the claim that the mid-frontal old/new effect is associated with the assessment of relative familiarity rather than absolute familiarity comes from Stenberg et al. (2008) comparing recognition of infrequent and frequent names. As infrequent names have a lower baseline familiarity, the increment relative to the baseline is higher than for frequent names. The mid-frontal old/new effect in the Stenberg et al. (2008) study was greater for infrequent names than for frequent names thereby possibly reflecting an "interaction between pre-experimental and experimental familiarity" (p. 87, de Chastelaine et al., 2009). As totally new concepts were created by means of the unitization instruction in the present study, it is well conceivable that absolute familiarity was assessed as it was more diagnostic of prior occurrence, and that this gave rise to the posterior distribution of the early old/new effect. Importantly, it is not argued that there are different neural familiarity signals reflecting absolute and relative familiarity, respectively. We rather promote the distinction between two different processes, one assessing the presence or absence of a familiarity signal (absolute familiarity) and the other assessing the increment in familiarity (relative familiarity). Even though this line of argumentation can account for the topographical distribution of the early old/new effect in the present study, the distinction between absolute and relative familiarity assessment, though theoretically plausible, is not yet a well approved finding and further research with a priori operational definitions of absolute and relative familiarity is required to delineate in more detail the mechanisms reflected by the early ERP old/new effect.

Note, that the latter two explanations are not necessarily mutually exclusive. The assessment of absolute familiarity might be a process which is driven by the ease of integration into pre-existing semantic knowledge. If semantic integration is feasible as reflected by conceptual fluency, then an item must have previously been encountered implicating absolute familiarity. And if additionally, the expected fluency of a stimulus is practically zero—as for pre-experimentally unfamiliar stimuli—the perceived fluency is diagnostic for a prior occurrence of the stimulus in the study phase. Reconciling the present data with previous studies, unitization leads to an enhancement of relative familiarity if it strengthens a pre-experimentally existing representation (e.g., Rhodes and Donaldson, 2007). However, if unitization produces a novel representation, other processes—such as the assessment of absolute familiarity or the attribution of facilitated conceptual processing to a prior experience with the event—seem to be activated.

Surprisingly, although the early old/new effect was significant only in the definition condition but not in the sentence condition, there was no significant interaction of Encoding Condition and Item Type in the early time window. Besides the possibility that the between-subjects variance in the encoding condition factor may have been too high to find a reliable interaction, the difference between encoding conditions could have also been obscured by a sporadically occurring additional associative familiarity signal caused by encoding-related interactive imagery of the scene described in the sentence (Rhodes and Donaldson, 2008).

Conclusions

In sum, the current encoding instructions led to a difference in the relative contribution of two different processes, one of which likely reflects familiarity and the other recollection. Recognition of word pairs in the definition condition was accompanied by an early old/new effect but no late parietal old/new effect suggesting that an encoding instruction that fosters unitization can encourage familiarity-based remembering in an associative recognition test. Conversely, recognition of word pairs in the sentence condition evoked a late old/new effect and a marginally non-significant early old/new effect. In conclusion, the current study shows that recollection is not necessary for associative recognition memory of unitized information. We argued that unitization—if resulting in a totally novel conceptual representation—can lead to the engagement of other forms of mnemonic processes like the assessment of absolute familiarity or conceptual fluency as a diagnostic means to distinguish between studied and non-studied stimuli. However, further research is required to delineate in more detail the mnemonic consequences of unitizations and the nature of the familiarity signal that is assessed during recognition judgments. In doing so, it is highly relevant to take into account which stimuli are used, how unitization is accomplished, and how participants approach the memory task.

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