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Multiple ways to the prior occurrence of an event: An electrophysiological dissociation of experimental and conceptually driven familiarity in recognition memory

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ABSTRACT

Recent research has shown that familiarity contributes to associative memory when the to-be-associated stimuli are unitized during encoding. However, the specific processes underlying familiarity-based recognition of unitized representations are still indefinite. In this study, we present electrophysiologically dissociable early old/new effects, presumably related to two different kinds of familiarity inherent in associative recognition tasks. In a study–test associative recognition memory paradigm, we employed encoding conditions that established unitized representations of two pre-experimentally unrelated words, e.g. *vegetable–bible*. We compared event-related potentials (ERP) during the retrieval of these unitized word pairs using different retrieval cues. Word pairs presented in the same order as during unitization at encoding elicited a parietally distributed early old/new effect which we interpret as reflecting conceptually driven familiarity for newly formed concepts. Conversely, word pairs presented in reversed order only elicited a topographically dissociable early effect, i.e. the mid-frontal old/new effect, the putative correlate of experimental familiarity. The late parietal old/new effect, the putative ERP correlate of recollection, was obtained irrespective of word order, though it was larger for words presented in same order. These results indicate that familiarity may not be a unitary process and that different task demands can promote the assessment of conceptually driven familiarity for novel unitized concepts or experimentally-induced increments of experimental familiarity, respectively.

1. Introduction

Recognition memory refers to the ability of becoming consciously aware that particular information has been encountered in a previous episode. There is an ongoing debate about the underlying processes contributing to recognition memory experiences. Single-process models posit that recognition memory involves just one type of memory varying on a unidimensional scale of global memory strength (Squire et al., 2007). In contrast, dual-process models advance the view that two processes are involved in recognition memory, namely familiarity and recollection (Mandler, 1980; Yonelinas, 2002).

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While recollection is an effortful and slow-acting process that provides information about an item along with the context of its occurrence, familiarity-based recognition is a fast-acting process by which the strength of a memory representation is assessed without the retrieval of qualitative or contextual details about the event. Meanwhile, there is extensive evidence in support of the dual-process account (see Aggleton and Brown, 2006; Yonelinas, 2002, for reviews) which has been established in formal models of recognition memory (e.g., Mandler, 1980; Aggleton and Brown, 1999, 2006; Yonelinas, 2001, 2002).

Dual-process accounts make relatively strong claims about the mechanisms underlying item and associative recognition memory. In particular, both familiarity and recollection are supposed to support item recognition judgments as an item can be judged as "old" due to recollection of information about the study episode or only because of its familiarity. Associative recognition memory tests require participants to distinguish between old and recombined pairs (studied items in new combinations). As the individual stimuli are equally familiar in both old and recombined pairs, familiarity cannot be diagnostic and recollection is required (e.g., Yonelinas, 1997; Hockley and Consoli, 1999; Donaldson and Rugg, 1998). However, this view has recently been challenged by studies showing that familiarity can support associative recognition under some circumstances, i.e. when the to-be-associated information is unitized (Yonelinas et al., 1999; Jäger et al., 2006; Rhodes and Donaldson, 2007, 2008; Quamme et al., 2007; Bader et al., 2010). Unitization refers to conditions in which separate items become represented as a unified whole (Graf and Schacter, 1989; Hayes-Roth, 1977). The current study was carried out to further explore characteristics of unitized associations and the mechanisms that support their retrieval.

Important insights into memory for items and associations have been revealed by event-related potential (ERP) studies (for reviews see Allan et al., 1998; Mecklinger, 2000; Rugg and Curran, 2007). In recognition memory studies, correct responses to old items elicit more positive-going ERPs compared to correctly rejected new items, commonly referred to as old/new effect. Even though the topic is still controversially discussed (Paller et al., 2007; Rugg and Curran, 2007), there is increasing evidence that this effect can be subdivided into an early mid-frontal effect between 300 and 500 ms and a somewhat later parietal effect between 400 and 800 ms. Both effects are sensitive to procedures commonly used for the operational definitions of familiarity and recollection, respectively (e.g., Curran, 2000; Yu and Rugg, 2010; Mecklinger et al., 2010). As the mid-frontal effect is generally reported for items with a high pre-experimental familiarity such as words or namable objects (but see also Curran and Hancock, 2007; Speer and Curran, 2007; Curran et al., 2002), it was suggested to reflect the increment in familiarity that results from the experimental exposure of these items relative to new items (Mandler, 1980; Stenberg et al., 2008). Both a mid-frontal and a parietal old/new effect are usually observed in item recognition tasks supporting the view that familiarity and recollection contribute to the retrieval of single items. By contrast, associative recognition of arbitrary information was found to elicit a late parietal old/new effect, only (Donaldson and Rugg, 1998; Jäger et al., 2006), supporting the view that memory for associations requires recollective processing.

However, more recent ERP studies challenge this view and indicate that familiarity can support memory for certain types of associations, i.e. unitized representations. Rhodes and Donaldson (2007) compared associative recognition for word pairs that were either pre-experimentally associated but not semantically related (traffic–jam), semantically related but not associated (violin–guitar) or both, semantically related and associated (lemon–orange). A mid-frontal old/new effect was only found for associated but not semantically related word pairs indicating that recognition of pre-experimentally existing associations can be based on familiarity. More recent findings suggest that the contribution of familiarity to associative recognition not only depends on the (pre-experimental) properties of the to-be-remembered information but also on encoding instructions. For example, Rhodes and Donaldson (2008) asked participants to imagine two words either individually (item imagery) or in an interactive manner (interactive imagery) intended to enhance unitization. The word pairs were either associated (traffic–jam) or semantically related (violin–guitar). A mid-frontal old/new effect reflecting familiarity was elicited under both encoding conditions for associated word pairs. By contrast, for semantic word pairs, the effect was only present after interactive imagery encoding. With regard to the late parietal effect, there was no interaction between encoding strategy and stimulus type. These results indicate that encoding instructions determine whether or not familiarity contributes to the recognition of conceptually (i.e., semantically) related word pairs.

Another, though related approach to examine unitization processes and how they affect memory retrieval is to use arbitrarily paired items and to encourage or discourage the unitization of the two words by the study instructions. Following this approach in a recent ERP study conducted in our lab (Bader et al., 2010), unrelated word pairs (vegetable–bible) were presented as separate lexical items either in a sentence frame (non-unitized word pairs: This vegetable was already mentioned in the bible) or together with a definition that combines the word pair to a new concept (unitized word pairs: A reference book which is consulted by hobby gardeners). We found a late parietal old/new effect, the ERP correlate of recollection, only following recognition of non-unitized word pairs. Interestingly, for the retrieval of unitized word pairs, we did not find the commonly observed mid-frontal old/new effect, but an early (350 to 500 ms) widespread distributed old/new effect with a maximum at parietal recording sites. We assumed that the integration of the two words into a new concept at study may have led to facilitated conceptual processing at test, which may have been attributed to the study phase and generated a conceptually driven familiarity signal. In fact, it has been argued that a feeling of familiarity arises if a perceived mismatch between actual and expected processing fluency is attributed to prior experience (Whittlesea and Williams, 1998, 2000, 2001). We assumed that as the new concept (vegetable–bible) was pre-experimentally unknown, facilitated conceptual processing was experienced as unexpected. By this, the enhanced conceptual fluency of the unitized pairs might have been the most diagnostic means during recognition and gave rise to an early parietal old/new effect for unitized pre-experimentally unknown word pairs. Support for this conceptual-fluency-view comes from other

ERP studies which found similar early parietal old/new effects for conceptually processed items with no pre-experimental representations (MacKenzie and Donaldson, 2007; Nessler et al., 2005) for which the assessment of conceptual fluency might also have been highly diagnostic. Notably, both aforementioned studies used encoding tasks that ensured conceptual processing of the faces, like face–name matching (MacKenzie and Donaldson, 2007) or fame judgments (Nessler et al., 2005). Moreover, the temporal and spatial distribution of the latter early old/new effect resembles closely the N400, an ERP component related to semantic integration processes (Kutas and Federmeier, 2000).

From this line of reasoning it follows that in recognition memory tasks, pre-experimentally novel and conceptually processed stimuli may be predominantly evaluated regarding the presence or absence of conceptual fluency to decide whether they are "old" or "new". Conversely, for experimentally familiar stimuli (i.e., stimuli already encountered before the experiment), existing memory representations are strengthened and the assessment of the experimentally-induced increment in familiarity (relative to new words) is the most diagnostic means for recognition judgments. The former process seems to be associated with an early and parietally focused old/new effect whereas the latter process is assumed to be reflected in the frequently reported early mid-frontal old/new effect. This implies that familiarity may not be a unitary electrophysiological and cognitive process. Even though familiarity is commonly defined in an exclusionary way, i.e. as recognition in the absence of recollection, this leaves open the possibility that familiarity has more than one computational basis and by this can be multiply determined. The relative contribution of both forms of familiarity to recognition memory judgments may depend on stimulus materials and task instructions.

The goal of the present study was to dissociate the putative ERP correlates of experimental familiarity and conceptually driven familiarity within the same study. In an associative recognition paradigm, word pairs were presented along with a definition that combines the two words into a new concept thereby enabling unitization. As in the Bader et al. (2010) study, we used an incidental memory paradigm to avoid any encoding strategies to interfere with the unitization instruction. In order to derive operational definitions of conceptually driven familiarity and experimental familiarity, the test phase included old pairs in the same order and in reversed order together with recombined word pairs (pairs of words that appeared in different pairings in the study phase) and completely new pairs (Fig. 4). A previous study showed that associative recognition was higher for same than for reversed pairs only after encoding instructions leading to unitization, in contrast to non-unitizing encoding instructions. These results indicate that the performance advantage of unitized associations disappears when word order is reversed (Haskins et al., 2008). Recombined pairs were included as control trials to ensure that participants did not decide on the basis of pure item recognition and did not enter the analyses of ERP and behavioral data.

Conceptual fluency was operationally defined as the processing difference between same pairs and new pairs. In more detail, we expected facilitated conceptual processing of

identically repeated (same) pairs, which were unitized into a new concept at study. As the fluent conceptual processing can be assumed to be unexpected for the previously unrelated word pairs, this is attributed to a prior encounter of this information. This should give rise to speeded recognition decisions and an early parietal old/new effect for same word pairs. Conversely, unitized representations cannot directly be accessed when reversed pairs are used as test cues (Haskins et al., 2008). Hence, conceptual fluency should not be diagnostic for these pairs. Instead, only the memory strength of the single words should be increased and this increment in familiarity should be assessed. Therefore, we expected an early mid-frontal old/new effect for reversed pairs. Regarding same word pairs, it is conceivable that also the assessment of incremental familiarity of single words operates in parallel to facilitated conceptual fluency. If this is the case, we expected an early mid-frontal effect in parallel to the early parietal effect for same pairs. Moreover, in line with previous associative recognition memory studies, we expected to find the late parietal old/new effect, the correlate of recollection-based recognition, due to contextual/associative retrieval in both conditions (Donaldson and Rugg, 1998; Rhodes and Donaldson, 2007, 2008).

2. Results

2.1. Behavioral data

Table 1 shows mean accuracy and response times of the four classes of test stimuli (same, reversed, recombined, new) and the discrimination scores for old/new judgments (Pr(old/new)) and for associative recognition judgments (Pr(associative)). An ANOVA performed on the accuracy data with the within-subject factor of Status (same, reversed, new) revealed a significant main effect [$F(2,34)=14.80$, $p<.001$]. Planned pairwise comparisons confirmed that same pairs were better recognized than reversed pairs [$t(17)=2.49$, $p<.05$]. New pairs were better recognized than same and reversed test pairs [$t(17)=3.43$, $p<.05$; $t(17)=4.71$, $p<.001$]. The ANOVA for reaction time measures also gave rise to a main effect of Status [$F(2,34)=11.86$, $p<.001$]. Planned pairwise comparisons showed that reaction times for same word pairs were faster than for reversed pairs [$t(17)=5.40$, $p<.001$]. The difference between same and new pairs was also significant [$t(17)=3.18$, $p<0.01$] while reaction times for reversed and new pairs did not differ significantly [$t(17)<1.74$].

Additionally, old–new discrimination indices and associative discrimination indices were analyzed, showing that both old–new and associative recognition discrimination were significantly above chance [$t(17)=8.22$, $p<.001$; $t(17)=3.53$, $p<.01$] and that old–new discrimination was higher than associative discrimination [$t(17)=4.71$, $p<.001$].

2.2. Electrophysiological data

Grand average ERPs at the three frontal and parietal sites elicited by correct responses to same, reversed, and new word pairs are depicted in Fig. 1a. As expected, word pairs correctly classified as old elicited more positive-going ERPs than

Table 1 – Means (SD) for accuracy, reaction times and discrimination indices. Note that the data for recombined pairs did not enter statistical analyses.						
Item status	Same	Reversed	New	Recombined	PR (old/new)	PR (associative)
RT (ms)	1358 (227)	1465 (222)	1445 (245)	1576 (249)	.75 (.13)	.65 (.17)
Accuracy (% correct)	86 (7)	81 (10)	92 (6)	79 (14)		
PR(old/new)=P(hit_same)+P(hit_reversed)/2−P(false alarms_new). PR(associative)=P(hit_same)+P(hit_reversed)/2−P(false alarms_recombined).						

correctly rejected new pairs. The ERPs started to differ as a function of Status at around 350 ms. Visual inspection indicated that in the early time window, a same=reversed>new pattern was obtained at frontal recording sites. Conversely at parietal sites, a same>reversed=new pattern was found. In the late time window, there was a topographically widespread old/new effect for reversed and same pairs, with a greater effect for same pairs (see Fig. 1a).

Fig. 1b depicts the topographic maps showing the distributions of the old/new effects in the early and late time window. As apparent from the figure, the old/new difference for reversed pairs is frontally accentuated whereas the old/new difference for same pairs shows a widespread distribution also covering posterior recording sites in the early time window. In the late time window the same vs. new and reversed vs. new differences were broadly distributed across the scalp.

A global ANOVA with the within-subjects factors of Status (same, reversed, new), Anterior–Posterior (frontal, parietal), Laterality (left, midline, right), and Time Window (early, late), yielded a significant main effect of Status $[F(2,44)=10.94, p<.001]$ and a significant interaction between Status, Time Window, Laterality, and Anterior–Posterior $[F(4,88)=3.45, p<.05]$. This interaction suggests that the old/new differences for same and reversed word pairs differ in the two time windows and also as a function of the two topographical factors. In the following, the interaction will be decomposed by analyzing old/new effects separately for each time window.

2.2.1. Early time window (350–500 ms)

An initial ANOVA including the factors of Status, Laterality, and Anterior–Posterior revealed a significant main effect of Status $[F(2,34)=6.82, p<.01]$ and a marginally significant three-way interaction between Status, Anterior–Posterior, and Laterality $[F(4,68)=2.39, p<.06]$. Based on this interaction, separate analyses and pairwise comparisons at frontal [F3, Fz, F4] and parietal [P3, Pz, P4] recording sites were conducted.

2.2.1.1. Frontal electrodes.

For the frontal recording sites, an ANOVA including the factors of Status and Laterality revealed a main effect of Status $[F(2,34)=6.76, p<.01]$. In a next step, the old/new effects for same and reversed pairs were analyzed separately.

An ANOVA (Status×Laterality) for same and new pairs revealed a significant main effect of Status $[F(1,17)=9.82, p<.05]$. An effect of Status $[F(1,17)=8.81, p<.05]$ was also found when reversed and new test pairs were analyzed. The ERPs elicited by same and reversed pairs did not differ

$[F(1,17)<4.45]$. These results confirm the observed same=reversed>new pattern at frontal recording sites.

2.2.1.2. Parietal electrodes.

The initial ANOVA including the factors Status and Laterality revealed a significant main effect of Status $[F(2,34)=4.72, p<.05]$ and a significant interaction between Status and Laterality $[F(4,68)=4.84, p<.01]$. Subsidiary analyses were conducted as before.

A significant main effect of Status $[F(17,1)=21.26, p<.001]$ embedded in a significant interaction between Status and Laterality $[F(34,2)=5.64, p<.01]$ emerged from the ANOVA comparing same and new test pairs. The interaction reflects the fact that the differences between same and new pairs were larger at electrodes P4 $[t(17)=3.37, p<.01]$ and Pz $[t(17)=3.34, p<.01]$ than at electrode P3 $[t(17)=2.28, p<.05]$.

No significant main effect but a significant interaction was found in the ANOVA comparing reversed and new pairs $[F(34,2)=5.74, p<.01]$. Direct contrasts between reversed and new pairs were not significant at any of the parietal electrode sites [p-values>0.12]. Separate ANOVAs for reversed and new pairs revealed a main effect of Laterality for reversed pairs $[F(34,2)=3.62, p<.05]$, but not for new pairs $[F(34,2)<3.28]$.

The ANOVA comparing same and reversed pairs at parietal sites revealed a significant main effect of Status $[F(17,1)=6.12, p<.05]$. As apparent in Fig. 1a, these results confirm the above described same>reversed=new pattern at parietal electrodes. Larger mean amplitude differences at P4 and Pz than P3 indicate that the early parietal old/new effect found for same pairs is right-lateralized.

In sum, early old/new effects for same and reversed pairs are comparably prominent at frontal electrodes. At parietal recording sites, a different pattern was found: Reliable old/new effects were only obtained for same test pairs but not for reversed pairs and same pairs elicited more positive-going ERPs than reversed pairs (see Fig. 2).

2.2.2. Late time window (500–800 ms)

An initial ANOVA including the factors Status, Laterality, and Anterior–Posterior revealed a significant main effect of Status $[F(34,2)=12.19, p<.001]$. To further follow-up the effect of Status, pairwise comparisons were conducted.

As illustrated in Fig. 1, significant main effects of Status emerged from the ANOVAs (Status×Anterior–Posterior×Laterality) contrasting same and new pairs $[F(17,1)=19.23, p<.001]$, reversed and new pairs $[F(17,1)=8.71, p<.01]$, as well as same and reversed pairs $[F(1,17)=4.48, p<.05]$. In sum, these results confirm that the late old/new effects were broadly

a

b
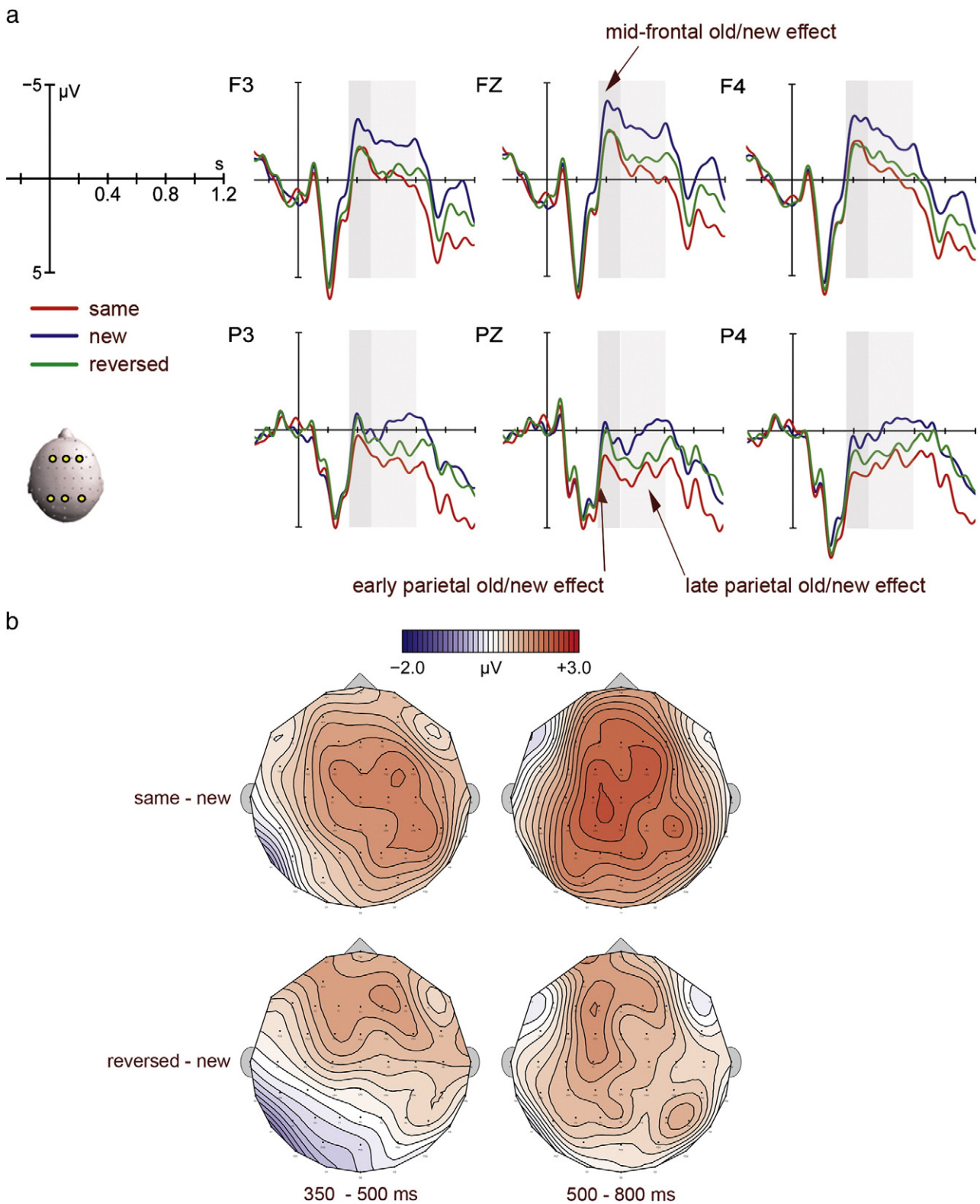
Fig. 1 – a. Old/new effects at the three frontal (F3, Fz, F4) and parietal (P3, Pz, P4) electrodes. Analyzed time windows are shaded. b. Topographic maps showing the scalp distribution of the same minus new difference and reversed minus new difference in the early time window (350–500 ms) and in the late time window (500–800 ms). The figure shows two different topographies for same–new and reversed–new in the early time window; a broadly distributed effect for same pairs and a mid-frontal old–new effect for reversed pairs. In contrast, maps show similar distributions for same–new and reversed–new effects in the late time window.
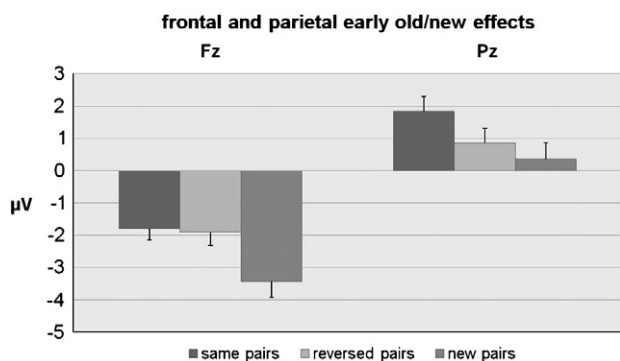
Fig. 2 – Mean amplitudes for same and reversed pairs at electrodes Fz and Pz in the early time window (350–500 ms) showing the same = reversed > new pattern at Fz and same > reversed = new pattern at Pz. Error bars represent the standard error of the mean.

distributed for old and reversed word pairs. Notably, there was a larger positivity for same than for reversed pairs.

2.3. Topographic analyses

Topographic analyses were performed for selected effects using rescaled data (McCarthy and Wood, 1985; Wilding, 2006). To the extent that the topographies of effects differ qualitatively, it can be concluded that the effects do not solely reflect differences in the time course or amplitude of a common neural population but are generated by at least partially dissociable neural systems (Rugg and Coles, 1995; Wilding, 2006). In a first step, we examined whether the early effects elicited by same and reversed pairs differ in topography. An ANOVA with the factors Status (same, reversed), Laterality, and Anterior–Posterior conducted for the same–new and reversed–new difference waves revealed a marginally significant interaction of Status and Anterior–Posterior [$F(1,17) = 3.55$, $p < .08$]. This suggests that the two early effects can be topographically dissociated and arose from at least partially dissociable neural generators.

In a second step, we directly contrasted the scalp topographies of the early and late effects for same pairs. The ANOVA with the factors Time Window (early and late), Laterality, and Anterior–Posterior conducted for the same–new difference waves revealed a significant two-way interaction of Time Window and Laterality [$F(2,34) = 6.89$, $p < .01$] and a significant three-way interaction [$F(2,34) = 8.64$, $p < .001$] suggesting that dissociable neural populations contributed to the early and late old/new effects for the word pairs presented in identical order. However, the interpretation of the latter interaction is clouded by the fact that there is a superposition of two effects in the early time interval.

Finally, we explored whether the old/new effects for same and reversed pairs in the late time interval differed topographically from the late positive difference between same and reversed word pairs. The ANOVAs contrasting the same–new and reversed–new difference waves with the same–reversed difference wave in the late time window did not

reveal significant interactions of the factor Status involving the Laterality and Anterior–Posterior factors [all p-values > .25]. This indicates that the same neural populations contributed to the old/new effects for same and reversed pairs and the late positivity to same pairs relative to reversed pairs.

2.4. Post-hoc analyses according to plausibility ratings

It is reasonable to assume that the assessment of conceptually driven familiarity for the unitized word pairs is modulated by the ease of unitization at study. In fact, we assumed conceptual fluency to be higher and thus reaction times to be faster and the early parietal old/new effect to be enhanced for word pairs which can easily be combined to a new concept on the basis of the definition given at study compared to those words for which unitization is experienced to be more difficult. To test this assumption we subdivided the word pairs for each subject in pairs with plausible and implausible definitions on the basis of the plausibility judgments given in the study phase.[1]

Next, we analyzed reaction times of same and reversed pairs as a function of plausibility judgments, respectively. Analyses showed that pairs with plausible definitions were recognized faster than pairs with implausible definitions when pairs were presented in same order [$t(17) = 3.517$, $p < .01$] but not when presented in reversed order [$t(17) < 1.74$] supporting the view that conceptual fluency was enhanced when unitization was easier.

In a next step, we contrasted the early parietal old/new effect, the putative correlate of conceptually driven familiarity for same pairs with plausible and implausible definitions. Due to an insufficient number of trials (<9 in at least two of the critical conditions) three subjects had to be excluded from this analysis.[2] We expected the early parietal old/new effect, the putative correlate of conceptually driven familiarity, to be larger for easily unitized (plausible) word pairs. Two ANOVAs with the factor Status (same, new) were performed for plausible and implausible pairings for same pairs at the three parietal electrodes [P3, Pz, P4] at which the early parietal effect was largest. Supporting the view that the early parietal old/new effect for same pairs is modulated by the ease of unitization, there was a main effect of Status [$F(1,14) = 10.30$, $p < .01$] for plausible but not for implausible pairs [$F(1,14) < 4.60$].

We also assumed that to the extent to which the early frontal old/new effect to reversed pairs is driven by the memory strength of single words, it should not be modulated by the experienced ease of unitization at study. In fact, there were reliable effects of Status (reversed, new) at the three

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[1] In these analyses, definitions rated as describing the pair well or very well during study were regarded as "plausible" and definitions rated as describing the pair rather badly or very badly were regarded as "implausible". Analyses were based on the second rating at study.

[2] Mean numbers of analyzed trials were 15.3 (range 8–22) for same "plausible" pairs, 14.6 (range 7–22) for same "implausible" pairs, 15.0 (range 9–28) for reversed "plausible" pairs, 13.7 (range 4–21) for reversed "implausible" pairs and 31.8 (range 18–40) for new pairs.

frontal electrodes [F3, Fz, F4] at which the early mid-frontal effect was largest. This effect was marginally significant for plausible [F(1,14)=3.88, p=.069] and significant for implausible pairings [F(1,14)=4.74, p<.05].

The results of this post-hoc analysis are summarized in Fig. 3. They show that the experienced plausibility of the definition at study selectively modulated the parietal old/new effect but not the mid-frontal old/new effect. This supports the view that the ease of unitization at study fosters the assessment of conceptually familiarity during recognition.

3. Discussion

The goal of the present study was to explore electrophysiological correlates of two putatively different forms of famil-

Fig. 3 – a. Differences between new and same pairs, for which the corresponding definitions were rated as "plausible" or "implausible" at electrode Pz. Error bars represent the standard error of the mean. b. Differences between new and reversed pairs, for which the corresponding definitions were rated as "plausible" or "implausible" at electrode Fz. Error bars represent the standard error of the mean.

iarity within the same associative recognition memory task. In more detail, we investigated ERP correlates of experimental familiarity for single words and conceptually driven familiarity for pre-experimentally novel concepts. In an incidental memory task, participants encoded semantically unrelated word pairs presented twice along with a definition combining the two words into a novel concept. In the subsequent test phase, participants were required to respond "old" to word pairs presented in the same or reversed order as compared to the study phase and "new" to recombined and completely new word pairs.

As the unitized word pairs were pre-experimentally novel, we assumed that the conceptual fluency present for word pairs repeated in identical order is unexpected and therefore is attributed to the prior encounter of these words in the study phase. On the basis of the findings of Bader et al. (2010), we expected speeded processing of these events relative to non-unitized word pairs and an early and parietally focused old/new effect. Conversely, conceptual fluency should not be diagnostic for word pairs presented in reversed order at test because they do not trigger the retrieval of the unitized memory representation formed during encoding. Rather, due to the high pre-experimental familiarity of the single words we expected the increment in familiarity relative to unstudied (new) words to be reflected in an early mid-frontal old/new effect for reversed pairs. Our results are to a large extent consistent with these predictions.

3.1. The early old/new effects: conceptually driven familiarity and experimental familiarity

We found a statistically reliable early old/new effect between 350 and 500 ms showing qualitatively different topographical distributions for same and reversed pairs. As the same "old" response was required for both types of word pairs, this difference in the early old/new effect cannot be attributed to different response criteria or strategies. Rather, we assume that two different processes contributed to recognition judgments for both word pairs in this time interval, one assessing the facilitation in conceptual processing, the other assessing the experimentally-induced increment in familiarity for single words.

The widespread distribution of the early old/new effect elicited by same pairs presumably reflects the overlapping effects of experimental familiarity (frontal) and conceptual fluency (parietal) in this early time window. This implies that even though same word pairs at test were conceptually more fluent due to the instruction to unitize the two words at study, the repetition of single words at test, similar as for reversed pairs, may have given rise to an increment in experimental familiarity that elicited the frontally distributed old/new effect. Conversely, the assumed ERP correlate of conceptual fluency was unique for same pairs and disrupted by reversing word order at test.

Several lines of evidence further support the conceptual fluency account for the early parietal effect for same words. First, the topographic and temporal distribution of the early effect for same words resembles the N400 component, an ERP component that is sensitive to conceptual–semantic processing (Kutas and Federmeier, 2000). The N400 is generally found
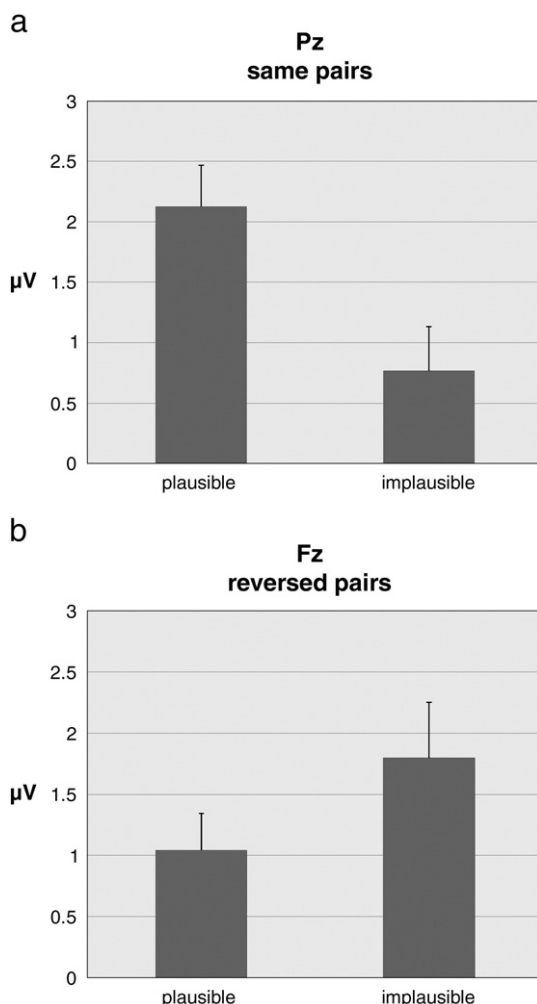
to be reduced when conceptual–semantic processing is facilitated by a preceding context. Even though the N400 is independent of correct recognition memory judgments (Olichney et al., 2000), it has been shown that enhanced conceptual fluency in a test phase of a recognition memory task (induced by a predictive sentence stem) is associated with an attenuated N400 and an enhancement of correct and incorrect "old" responses (Wolk et al., 2004). It was proposed that facilitated processing—if unexpected—is attributed to a prior occurrence of the event and by this can increase familiarity (e.g., Whittlesea and Williams, 1998, 2000, 2001). Consistent with this view, we assume that facilitated processing of the unitized word pairs in the same condition was indeed highly unexpected due to their pre-experimental novelty and by this gave rise to an N400 attenuation and an increase in familiarity. It is reasonable to assume that familiarity is driven by the ease of integration into semantic knowledge of a pre-experimentally unfamiliar stimulus. As a stimulus must have been previously encountered to enable semantic integration, perceived conceptual fluency can be diagnostic for its prior occurrence.

Second, an early parietal old/new effect was previously found for pre-experimentally unfamiliar stimuli such as faces of unknown individuals that were processed on a conceptual level during encoding (MacKenzie and Donaldson, 2007; Nessler et al., 2005). MacKenzie and Donaldson discussed this effect as a correlate of the assessment of absolute familiarity, an explanation which is compatible with our conceptual fluency interpretation. Absolute familiarity can be diagnostic in a recognition task if there was no pre-experimental familiarity. Hence, the assessment of absolute familiarity might be driven by the ease of integration into preexisting conceptual–semantic knowledge and associated with the experience of unexpected conceptual fluency.

Third, post-hoc analyses of the early old/new effects indicate that the parietal effect for same pairs, the putative ERP correlate of conceptually driven familiarity, was influenced by the experienced ease of unitization at study. No such effect was obtained for the mid-frontal effect to reversed pairs. This suggests that the ease of unitization experienced in the study phase fosters conceptual fluency and fluency driven familiarity during the test phase.

Finally, consistent with our predictions faster reaction times for same pairs relative to reversed pairs indicate facilitated conceptual processing of these pairs at test. However, an objection against this argument could be that the observed reaction time advantage could also result from a perceptual repetition effect as the same pairs were the only condition in which the study pairs were repeated in identical order. If our interpretation is correct, the reaction time advantage for same over reversed pairs should not occur when word pairs are not unitized at study. To test this assumption, we conducted an additional behavioral follow-up study (n=18), in which a sentence encoding paradigm was used in order to hinder unitization. Participants studied the two words of a pair as separate lexical items within a sentence frame (e.g., *This vegetable was already mentioned in the bible*, see Bader et al., 2010) and were tested under the same conditions as in the current experiment. Consistent with our prediction, there was no response speed advantage for same over

reversed pairs after sentence encoding.[3] This finding strongly speaks in favor of a fluency effect which was generated by conceptual integration (unitization) during definition encoding and against a mere effect of perceptual repetition.

Additional evidence in line with our reasoning is that responses were faster for same pairs when the pair's definition was rated as plausibly describing the concept in contrast to pairs with implausible definitions while this was not the case for reversed pairs. Supposedly, plausibility of the definition enhanced unitization during encoding, which may have further facilitated conceptual processing of the novel concept at test.

Although the present results indicate that the attenuation of the N400 may relate to conceptually driven familiarity, they also suggest that this is not the only mechanism that allows determining whether an event was previously encountered. The specific task conditions to unitize two unrelated words into a novel concept may have fostered participants to rely on conceptual fluency as a diagnostic means for recognition judgments. However, the finding of a mid-frontal old/new effect for repeated words in the reversed and the same conditions suggest that a second mechanism assessing the increment in experimental familiarity (i.e., the memory strength of well-known items that is increased during the experiment) is at work either independently or in parallel to conceptually driven familiarity. Thus, familiarity can be multiply determined and does not relate to a unitary ERP correlate. Note that assessing the increment in experimental familiarity is not sufficient to solve an associative memory task as the increment in experimental familiarity should be similar for all word pairs composed of previously studied words (same, reversed, and recombined pairs). Rather, successful associative recognition memory requires recollection. The finding of a late parietal old/new effect for same and reversed pairs is consistent with this view (see below).

While we interpret the mid-frontal ERP old/new effect as reflecting experimental familiarity, others have suggested that it more likely reflects conceptual priming—the facilitation of behavior due to prior access to related meaning (e.g., Voss and Paller, 2006, 2007; Paller et al., 2007; Voss et al., 2010a,b). For example, Voss et al. (2010a,b) argued that the perceived meaningfulness of the stimuli determined the amount of conceptual priming in a behavioral task as well as the presence of the mid-frontal old/new effect. However, if the mid-frontal effect was related to conceptual priming in the current experiment, we would expect it to be more pronounced for same pairs than for reversed pairs as only same pairs triggered the retrieval of a novel, unitized concept that was established during encoding. This is in contrast to our results. We show that the mid-frontal effect was unaffected by the order of the retrieval cue, which in turn affected

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[3] Reaction times for same (M=1385 ms, SE=45) and reversed pairs (M=1418 ms, SE=42) did not differ significantly [t(17)<1.74] in the sentence condition. Moreover, a t-test showed that the same/reversed-difference was significantly smaller after sentence (M=33 ms, SE=21) than after definition encoding [M=107 ms, SE=20; t(34)=2.58, p<.05].

conceptual processing. However, it can be argued that the findings by Voss et al. (2010a,b) are reconcilable with our proposal that the mid-frontal old/new effect reflects the increment in experimental familiarity as this is only possible for pre-experimentally familiar (meaningful) stimuli.

Still another account of the early parietal effect could be that it reflects early-onsetting recollection. Using a recognition memory task with multiple study–test repetitions in which the same items were studied four times, de Chastelaine et al. (2009) found an early-onsetting, parietally distributed old/new effect between 240 and 260 ms with increasing test repetitions suggesting that recollection was elicited at earlier latencies after multiple study–test repetitions. While the early-recollection account makes much sense for the paradigm used in the de Chastelaine study, we think that it cannot account for the early parietal effect in the present study. First, the current early parietal effect is observable already after one study–test cycle (see also Bader et al., 2010). Second, we found an early parietal effect only for same, but not for reversed pairs while the late parietal old/new effect is similar in time course and scalp distribution for same and reversed pairs. This finding is also difficult to reconcile with an early-recollection view.

3.2.   *The late old/new effect—recollection-based recognition*

Replicating various findings from ERP associative memory studies (e.g., Donaldson and Rugg, 1998; Rhodes and Donaldson, 2007), we found a reliable late old/new effect for reversed and same word pairs suggesting that recollection contributed to recognition judgments in both conditions. Although this late old/new effect showed a rather widespread topography, it can be assumed to reflect recollective processing as it was statistically highly reliable at parietal sites, where it is commonly observed (Donaldson and Rugg, 1998; Mecklinger and Jäger, 2009).

Our results, however, are inconsistent with the findings from Bader et al. (2010) and Jäger et al. (2006), who found no ERP correlate of recollection when unitized information was remembered. Bader et al. (2010) used a triple response procedure (old, recombined, new) by which it was possible to distinguish between old, recombined, and new pairs on the basis of conceptually driven (old > recombined and new) or experimental familiarity (old and recombined > new). As in the present study reversed and recombined pairs were composed of two previously encountered words, the increment in experimental familiarity was not diagnostic to differentiate between reversed and recombined pairs. Therefore, adequate decisions for reversed and recombined pairs may have required recollection of further elements of the study episodes. Moreover, each word pair was presented twice in the present study whereas only once in the studies by Bader et al. (2010) and Jäger et al. (2006). It is well conceivable that this repeated presentation of the word pairs at study has strengthened memory representations and in turn reinforced recollective processing for same pairs which became evident in an enhanced late parietal old/new effect (Finnigan et al., 2002). Notably, a late positivity was also obtained for same pairs relative to reversed pairs. A topographical profile analysis revealed that this late positivity did not differ in scalp topography from the old/new effects for same and reversed pairs. This suggests that the neural populations mediating recollective processing were engaged to a larger extent for same pairs than for reversed word pairs, although both types of old word pairs had to be classified as old and by this, there were no explicit requirements to discriminate between same and reversed repetitions of word pairs.

4.   Conclusions

The current study revealed two distinct electrophysiological correlates of familiarity within one experimental design: Consistent with a large variety of previous studies, we found an early mid-frontal old/new effect for same and reversed word pairs that is thought to be associated with experimental familiarity for pre-experimentally familiar stimuli. Conversely, conceptually driven familiarity for novel concepts is postulated to be associated with a topographically distinct early parietal old/new effect. In line with Whittlesea and Williams (2001), it was argued that the unexpected experience of conceptual fluency for novel unitized concepts led to a feeling of familiarity only if word pairs were presented in the same order as at study. These results indicate that the nature of familiarity signals is not unique but may depend on specific encoding and retrieval requirements. Admittedly, the stimulus material we used was quite unique and the observed old/new effects might be highly specific. Future research is required to further elucidate the characteristics of experimental conditions initiating different forms of familiarity preferably by using other operational definitions of familiarity and recollection and to incorporate the current findings in more general accounts of recognition memory.

5.   Experimental procedures

5.1.   *Participants*

Twenty-three native German speakers participated in the experiment after giving informed consent. Data from five participants were discarded due to an insufficient number of artifact free trials (<16) in at least one of the critical test pairs' conditions (same, reversed, recombined, new). The mean age of the remaining 18 participants (10 females) was 22.18 years (range: 19–26). All participants were right-handed as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971) and had normal or corrected to normal vision. The participants obtained payment at a rate of 8 Euros per hour and were debriefed after the experiment.

5.2.   *Material*

The material of the study phase consisted of 126 unrelated German word pairs and corresponding definitions. The single words, chosen from the CELEX database (Baayen et al., 1993), were moderately frequent nouns (10–500 occurrences per million) restricted to a word length of 4–10 letters. In the encoding phase, the word pairs were presented with definitions to help participants to form a new concept out of two previously unrelated words. The definitions were composed of

a noun phrase and a relative clause containing 5–10 words. The actual target words were not repeated in the definition sentence. In order to exclude pre-experimentally associated word pairs, a pilot rating study (N=59) was conducted, which assured that the two words supposed to build a new concept were indeed semantically unrelated, as assessed by a 4-point scale. Only word pairs rated as unrelated were included in the experiment (i.e. word pairs rated as "rather unrelated" or "unrelated"). In an attempt to increase recognition memory performance, all word pairs and their respective definitions were presented twice in the study phase. The study list was pseudo-randomized with the constraint that identical word pairs were repeated with gaps of 10–30 items in between.

The test phase included 168 pairings: 42 *same pairs*, which had been presented in the study phase in exactly the same order, 42 totally *new pairs*, of which both words had not been seen before, 42 *reversed pairs*, which consisted of the same words as in the study phase, but were presented in a changed order and finally 42 *recombined pairs*, which were new combinations of words presented in the study phase together with another partner. The latter condition was necessary to avoid that participants were able to discriminate between old and new pairs on the basis of pure item recognition instead of associative recognition.

To ensure that every specific word pair appeared in each of the three "old" conditions with equal probabilities across participants, stimuli for the test phase were constructed by dividing the study pairs into three item groups. Within these groups, pairs were same, reversed and recombined, respectively. Test lists were arranged by using one same, one reversed and one recombined set of the different item groups together with 42 new pairs (equal in all test lists), resulting in three different test lists, which were permuted across participants. An additional rating study was conducted, in which participants (N=42) judged the semantic relation of the recombined and new pairs in order to assure that these pairings fulfilled the same criteria as the word pairs of the study list. Based on this rating, two recombined pairs were modified by recombining the words to new pairings. Concerning the new pairs, all 42 included pairs were rated to be unrelated. The test list was pseudo-randomized with the constraint that not more than three pairings from the same type of test pairs were presented in succession. All test lists were divided into two blocks including 21 pairings of each test condition in each block.

5.3.　Design and procedure

The experiment was designed using E-Prime (Psychology Software Tools). Participants were seated in front of a standard PC with a 19 in. monitor at a distance of approximately 80 cm. Stimuli were presented in white letters on a black background. Word pairs in the study phase were presented next to each other in upper-case letters (Arial 24 font), separated by two blanks. The definitions were simultaneously displayed (Arial 20 font) underneath the two words. During the test phase, word pairs (without definition) were presented next to each other in the same font, size and spacing as in the study phase. To minimize eye movements, stimuli were presented as close as possible to the center of the screen.
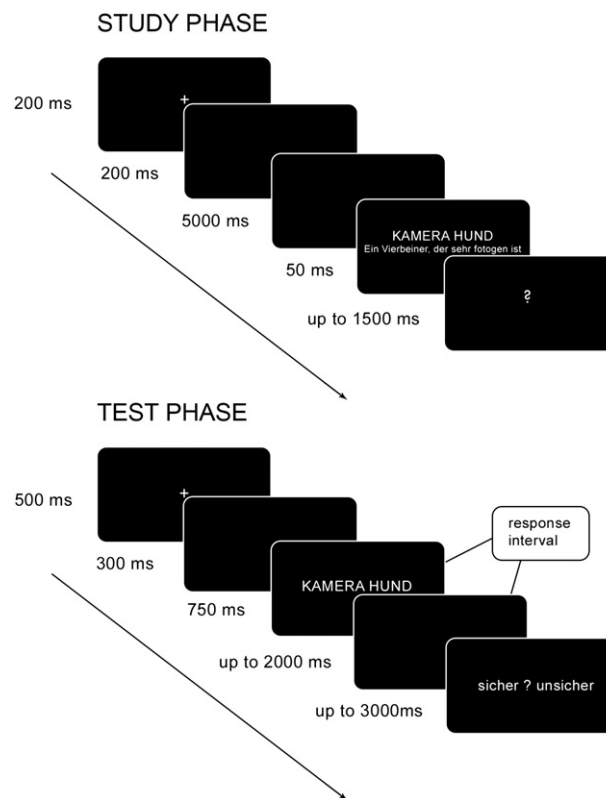
Fig. 4 – Trial structure of study and test phase. The task at study was to rate the plausibility of the definition to describe the concept (*CAMERA–DOG. A four-legged animal that is very photogenic.*). Responses had to be made during the response interval after the stimulus presentation. The task at test was to discriminate between "old" and "new" pairs. "Old" pairs were presented in the same pairing as during study, either forward or backward (old and reversed pairs). "New" pairs included pairs consisting of previously encountered words but in new combinations (recombined) and totally new pairs (new). After giving their response, participants had to make a confidence judgment (sure or unsure).

During the study phase (see Fig. 4), participants were required to rate the plausibility of the definition to describe the word pair as a new concept on a 4-point scale, ranging from 1 ("very badly") to 4 ("very well"). Each stimulus was presented for 5000 ms, preceded by a fixation cross (200 ms) and a blank screen baseline period (200 ms). The stimulus was followed by a blank screen (50 ms) and the response window (1500 ms). A question mark cued participants to respond by pressing the keys "x", "c", "n", and "m" on a keyboard using middle and index fingers of both hands. After each 42 trials, there was a self-paced break. The study phase was followed by a 5-min-retention interval, in which participants performed a distracter task (detecting a specific combination in a series of characters). Afterwards, participants were informed about the forthcoming recognition memory task.

In the test phase (see Fig. 4), participants were asked to decide whether the presented word pair was old or new by pressing the keys "c" and "m" using their index fingers of both hands. The key assignment was counterbalanced across

participants. "Old" responses were required for same and reversed pairs and "new" responses for recombined and new pairs. Each test pair was preceded by a fixation cross (500 ms) and a blank screen baseline period (300 ms) and was presented for 750 ms, followed by a blank screen (2000 ms). The response window started at stimulus onset and ended along with the key press or with the offset of the blank screen. Subsequently, participants were required to make a confidence judgment ("sure" or "unsure") about their prior decision during a time window of maximally 3000 ms, which terminated at the time of the key press. As in the study phase, there was a self-paced break after each 42 trials.

5.4. Data acquisition and processing

EEG was continuously recorded from 58 Ag/AgCl electrodes embedded in an elastic cap according to the extended 10–20 system (Sharbrough et al., 1991) in an acoustically and electrically shielded dimly lit chamber. All EEG channels were amplified with a band pass from DC to 70 Hz at a sampling rate of 500 Hz with a right mastoid reference and were re-referenced offline to linked mastoids. AFz was the ground electrode. To control for vertical and horizontal eye movements, the electrooculogramm (EOG) was recorded from right sub- and supraorbital ridges (VEOG) and from the outer canthus of each eye (HEOG). Electrode impedances were kept below 5 kΩ. Data was recorded with BrainVision Recorder V1.02 (Brain Products) and processed using EEProbe (ANT Software). Eye-movements were corrected by means of a linear regression algorithm and epochs including other recording artifacts were rejected before averaging. Mean numbers of analyzed trials were 30.2 (range 20–38) for same pairs, 28.9 (range 20–39) for reversed pairs, and 32.1 (range 19–41) for new pairs. For ERP averaging, continuous EEG data was separated into 1500 ms epochs, including a 300 ms baseline. Analyses were performed on mean voltage data relative to the pre-stimulus baseline period. Before averaging, the baseline was subtracted from each data point. For the ERPs presented in Fig. 1a, a 12 Hz low pass filter was applied.

5.5. Data analysis

Data were analyzed with repeated-measures analyses of variance (ANOVA). The Greenhouse–Geisser (Greenhouse and Geisser, 1959) adjustment for non-sphericity was used where appropriate and the corrected p-values are reported together with the uncorrected degrees of freedom. Probability values (p-values) for follow-up analyses were adjusted applying Holm's sequential Bonferroni correction (Holm, 1979). The significance level was set to $\alpha = .05$. All ERP analyses were conducted only on correct responses.

As responses for recombined pairs were not relevant in light of our hypotheses, they were excluded from all ERP analyses. For reasons of completeness, accuracy and response times for recombined pairs are reported in Table 1. As the single items of the pairs are presented separately in the test phase, the processing of a recombined pair may have interfered with the prior occurrence of the study phase partner. Lower accuracy and longer response times for recombined pairs support this view (see Table 1).

Statistical analyses of behavioral data included ANOVAs conducted with the factor test pair Status (same, reversed, new). The proportion of correct responses (mean accuracy) and reaction times served as dependent variables. Additionally, old–new discrimination scores (Pr: $P_{hit} - P_{false\ alarms\ "new"}$) and associative discrimination scores (Pr: $P_{hit} - P_{false\ alarms\ "recombined"}$) were computed (Snodgrass and Corwin, 1988) and analyzed.

ERPs in the test phase were quantified as mean amplitudes in two consecutive time windows (350–500 ms and 500–800 ms) supposed to tap the early frontal and parietal old/new effect and the late parietal old/new effect, respectively. Three frontal [F3, Fz, F4] and parietal [P3, Pz, P4] electrodes, at which the early and late ERP effects were largest, were used for statistical analyses. The selection of the time windows and electrodes for ERP analyses was based on visual inspection of the waveforms and on previous studies investigating old/new effects in associative memory tasks (Rhodes and Donaldson, 2007; Bader et al., 2010; Opitz and Cornell, 2006).

To analyze ERP old/new effects, an initial higher level ANOVA was conducted with the factors Status (same, reversed, new), Time Window (350–500 ms, 500–800 ms), Anterior–Posterior (frontal, parietal), and Laterality (left, midline, right). Time window and/or location specific follow-up analyses were conducted whenever there were significant interactions involving the factor Status. For reasons of clarity, only significant main effects or interactions involving the factor Status are reported.

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