Using Unitization as Encoding Strategy in Associative Recognition Memory: Behavioral, fMRI, and ERP Evidence

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Abstract

Recognition memory is thought to depend on two processes. Whereas familiarity refers to a simple feeling of knowing a stimulus, recollection enables us to remember associative information such as the place of a particular episode in which the stimulus has occurred. Accordingly, recollection, which relies on the integrity of the hippocampus, is generally required to remember arbitrary associations. In contrast, a familiarity signal, presumably arising in the perirhinal cortex, is sufficient to recognize single items. However, it was shown that the integration of separate items into a single configuration (unitization) leads to reduced involvement of recollection and greater reliance on familiarity. Of special interest is the formation of novel units from previously arbitrary associations during a single encoding episode as this accomplishes the unique ability of episodic memory to remember associative information that relates to a specific event. This thesis reports four experiments in which retrieval processes for novel units were compared to those involved for arbitrary associations, pre-existing units and single items. Experiment 1 and 2 revealed behavioral and fMRI evidence that retrieval of arbitrary word pairs involves flexible recollection whereas retrieval processes relied on the exact configuration when word pairs were studied as novel conceptual units (e.g., *vegetable bible = a book consulted by hobby gardeners*). Hippocampal engagement during retrieval of novel units was reduced in contrast to arbitrary word pairs. Moreover, brain regions specific to the retrieval of novel units and single items were dissociated. Experiment 3 could not replicate previously reported familiarity-related ERP effects for novel conceptual units as well as pre-existing units (e.g., *tea cup*). Contextual factors influencing familiarity-based retrieval are discussed. The results from Experiment 4 provide preliminary evidence that arranging two unrelated objects as a scene can enhance familiarity for associations suggesting that not only contiguous entities can be perceived as units.

Mit Dir, Papa.

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Only a couple of years ago, I had never imagined to finish something like this. One of the most important reasons why it still happened is that there were people who believed in me. First and foremost, I would like to thank my supervisor Axel Mecklinger for his confidence in me, for the many discussions we had, for his support and not least for his enthusiasm for the “familiarities”. I am grateful to Hubert Zimmer not only for reviewing this thesis, but also for all his critical and helpful questions and comments on my work.

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Abbreviations

ANOVA	analysis of variance
BA	Brodmann area
BIC	binding-of-item-and-context
BOLD	blood-oxygen-level-dependent
CA	cornus ammonis
CLS	complementary-learning-systems
CR	correct rejection
CRAFT	convergence-recollection-and-familiarity theory
DD	domain-dichotomy
EC	entorhinal cortex
EEG	electroencephalogramm
ERP	event-related potential
FA	false alarm
fMRI	functional magnetic resonance imaging
HC	hippocampus
IFG	inferior frontal gyrus
ISI	inter-stimulus interval
K	know
M	mean
MANOVA	multivariate analysis of variance
mPFC	medial prefrontal cortex
MR	magnetic resoncance
MTL	medial temporal lobe
MTLC	medial temporal lobe cortices
n.s.	non-significant
PFC	prefrontal cortex
PhC	parahippocampal cortex
PPC	posterior parietal cortex
PrC	perirhinal cortex

R	remember
R/K	remember/know
rec	recombined
rev	reversed
RHV	representational-hierarchical view
ROC	receiver-operating-characteristics
sam	same
SE	standard error
VVS	ventral-visual stream

Introduction

Imagine we would not be able to store and retrieve associations between persons, objects, locations, and situations. The constant experience of our life would be an incoherent mixture of familiar and novel situations. The ability to remember associations is essential for episodic remembering. Episodic memory refers to the part of our memory system which is able to remember personal events such as when we were in the zoo to watch the lions for the last time. It lets us recall all kinds of event details as for example that it was rainy that day, what an awful smell it was in the lion house and what joy it was that there were lion babies. Episodic memory can also relate different events to each other such as knowing that the zoo visit was shortly after returning from the summer holidays two years ago. Thus, episodic memory gives us the opportunity to mentally travel back into our past (Tulving, 1985). In contrast, semantic memory covers knowledge about the world stored in a depersonalized way. For instance, we can tell that a lion naturally lives in Africa without having to remember where or when we have learned this information. Even more basically, semantic memory stores concepts (such as knowing what at all a lion is) and relates conceptual knowledge to each other (e.g., a lion and a tiger are both cats).

Just as episodic memory, semantic memory also involves remembering associations. However, it does this in a different way. Whereas in episodic memory associations have to be formed during a single episode (e.g., zoo and rain on a particular day), associations in semantic memory become manifest over time (e.g., lions and tigers occur consistently together in different contexts) (e.g. McClelland & Rogers, 2003). Moreover, remembering episodic associations is thought to necessarily engage the hippocampus (e.g., Aggleton & Brown, 2006) whereas semantic associations are assumed to be accessible by-passing the hippocampus (e.g., McClelland & Rogers, 2003; Moscovitch, Nadel, Winocur, Gilboa, &

Rosenbaum, 2006). This property of episodic memory transfers also to recognition memory, i.e. the ability to realize that we have encountered a stimulus before. Accordingly, the hippocampus is needed in order to recognize that we have encountered an arbitrary (i.e. not semantically related) association before (e.g., Turriziani, Fadda, Caltagirone, & Carlesimo, 2004). However, it was suggested that recognizing associations which were formed during a single episode does not rely on the integrity of the hippocampus when they are integrated into a single whole, i. e. are unitized (Quamme, Yonelinas, & Norman, 2007). The focus of this thesis is to follow-up this hypothesis comparing the processes involved in recognition memory for different kinds of associations using different behavioral and neuroimaging methods.

In Chapter 1, I give an overview of the research on recognition memory which is relevant to the research questions of this thesis. The focus lies on characterizing the two processes presumably subserving recognition memory: familiarity and recollection. I describe behavioral and electrophysiological methods to assess the two processes as well as findings regarding their neural grounding. The chapter ends with the attempt to relate recognition memory to the semantic and episodic memory systems. The second chapter provides the background in research on associative recognition memory including an elaboration on different kinds of associations in order to establish a basis for the question when associative memory can be independent of the hippocampus. Special focus is placed on the effects of unitization arguing that it is important to distinguish between different kinds of unitization, especially as different kinds of unitization seem to be differentially associated with semantic and episodic memory. Hence, Chapter 3 covers considerations in which way the mnemonic processing differs for these different types of associations. Before Experiments 1 to 4 are reported, I describe the deduction of the general research question of the present work in Chapter 4.

CHAPTER 1

Recognition Memory

Recognition memory refers to the ability of a "judgment of previous occurrence" (Mandler, 1980, p. 252). Thus, it is our constant task to realize whether we have encountered a specific person, object, smell, etc. ever before. Research on recognition memory has grown tremendously in the last decades. While many details of the underlying mechanisms of this ability are still controversial, there is also a lot of uncontroversial insight into this phenomenon. First of all, recognition memory (outside and inside of laboratories) is nothing else than performance of a task in which the participant has to decide whether he or she has encountered the presented stimulus before. By this, it is neither necessarily tied to one memory system nor to one specific psychological process. Moreover, it is generally regarded as a conscious product of memory meaning that it is an explicit cognition to recognize something or consider it as novel. Although further characterization is a matter of debate, this chapter gives a summarizing picture of current models of recognition memory. I start by explaining the basic set up of a recognition memory experiment.

1.1 Investigating Recognition Memory

A typical recognition memory experiment comprises a study phase and a test phase. In the study phase, participants learn a list of items either incidentally while completing a non-memory task on the items or intentionally encode the items for a subsequent memory test. In the test phase, the study list (old items) is intermixed with a list of unstudied items (new items). For each single item, the participant has to decide whether the item was presented during the study phase or not (old/new or yes/no judgment). Responses are then classified as hits (old items classified as 'old'), misses (old as 'new'), correct rejections (CR, new as 'new') and false alarms (FA , new as 'old'). Besides hit and correct rejection rates, the Pr value ($Pr = p(hits) - p(FA)$) is commonly reported as it reflects a measure of memory performance which is independent of response preference. Chance performance is described by $Pr = 0$. Response tendencies are quantified by the bias measure Br ($Br = p(FA)/(1 - PR)$), values below 0.5 indicating conservative responding (a tendency to say 'new') and values above 0.5 indicating rather liberal responding (Snodgrass & Corwin, 1988). From this basic experimental concept, an almost endless number of variations evolved, many of which occur in the following. Each variation is specifically useful to provoke a different composition of the contributing processes and memory systems.

1.2 Familiarity and Recollection

There is broad consensus that recognition memory involves two phenomenological aspects: recollection and familiarity (e.g., Wixted & Squire, 2011; Yonelinas, 2002). Recollection can bring to mind episodic details of an item's occurrence in the past whereas familiarity lacks such additional information and is just the feeling of knowing that an item has been encountered before. The currently prevailing dual-process view is that these two psychological phenomena are the expressions of two dissociable processes in the brain (for a review see Yonelinas, 2002). In contrast, the single-process account claims that it is one single process that underlies recognition memory, namely the assessment of a single (accumulated) memory signal which can result in different phenomenological experiences (e.g., Kirwan, Wixted, & Squire, 2008; Slotnick & Dodson, 2005; Squire, Wixted, & Clark, 2007). However, as becomes apparent in the following sections, the evidence in favor of the dual-process account of recognition memory is strong. Thus, the focus in the following is placed on the nature of the distinct processes of recollection and familiarity, their behavioral expressions and their underlying neural networks.

1.2.1 Familiarity and Recollection in a Nutshell

Familiarity is understood as an automatic process, the products of which are readily and rapidly available. Along these lines, it is characterized as minimally strategic and controllable. Mostly, familiarity is believed to operate only on single representations. Moreover, it is thought to be best described by signal-detection theory (D. M. Green & Swets, 1966). This means, each item has its own specific familiarity strength value whereby the distribution of the old item values is on average higher than the new items distribution. The distributions are assumed to be overlapping in most cases. A criterion determines whether a specific familiarity value leads to an 'old' or 'new' decision. The higher the familiarity value, the more confident the recognition decision. The distance between the old items and new items distribution is described by the parameter *d'*which can be used an indicator of the discriminability and the difference in familiarity between the two classes of items (see Figure 1.1.A). In contrast, recollection is generally described as a non-automatic more slowly operating effortful cognitive process. It is therefore considered to be more strategic and controllable. Its core function is to establish memory traces which link two or more separate elements. According to the dual-process signal detection model (e.g., Yonelinas, 1994, 1997), recollection is understood as an all-or-none threshold process. Having gathered a specific amount of evidence for the oldness of an item, a highly confident 'old' judgment is made. Otherwise, recollection completely fails and the item is rejected. Commonly, the form of the old item and new item distributions are not further specified. However, great variance above the threshold is normally not assumed. Thus, strong variations in confidence are not expected (see Figure 1.1.B). Mostly, familiarity and recollection are assumed to be independent implying that they can occur solo but also in parallel (Yonelinas, 2002; Yonelinas, Aly, Wang, & Koen, 2010).

1.2.2 The Assessment of Familiarity and Recollection with Behavioral Measures

In the following paragraph, I give a brief and non-exhaustive overview of the most common methods to assess familiarity and recollection on a behavioral level. These methods can be used in order to derive parameter estimates of how large the contributions of the two processes are under specific experimental conditions. Moreover, they are essential to investigate the neural networks underlying familiarity and recollection.

Receiver-Operating-Characteristic Curves

Receiver-Operating-Characteristic (ROC) curves depict the probability of a hit as a function of the probability of an FA at different levels of deci-

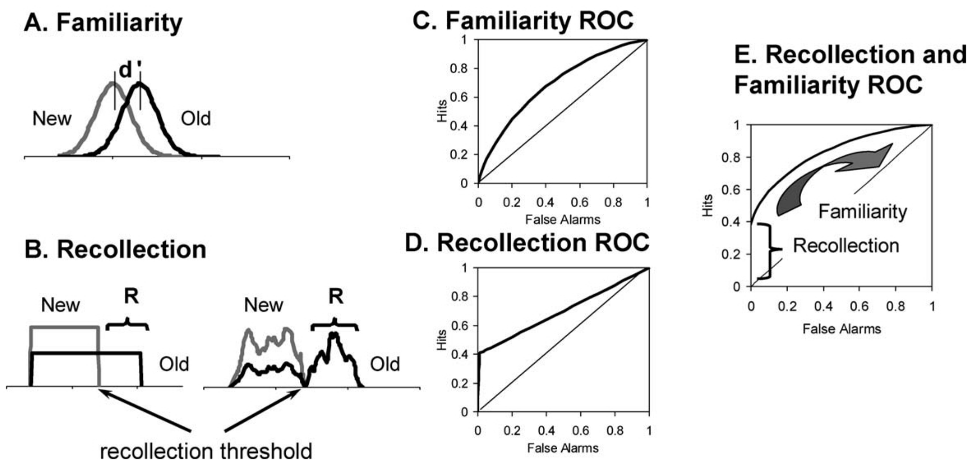


Figure 1.1.: Characterizing familiarity and recollection. (A) Familiarity as a signal detection process with two Gaussian distribution of familiarity strength for old and new items. The mean of the old distribution is higher than the mean of the new distribution (d' corresponds to the distance between the means). (B) Two possible types of distributions for the threshold process recollection. (C) ROCs for pure familiarity-based recognition. (D) ROCs for pure recollection-based recognition. (E) ROCs for recognition based on familiarity and recollection. This figure is reproduced from Yonelinas et al. (2010, p. 1180) with permission from John Wiley & Sons, Inc.

sion confidence. Increasing FA rates correspond to an increasingly liberal bias. In humans, these measures are obtained by asking participants to indicate their confidence levels with each response on a 6- or 10-point scale whereby one half covers 'old' responses and the other half 'new' responses. Values range from 'very confident old' to 'very confident new'. Thus, a conservative bias can be mimicked by difining only 'very sure old' responses as 'old' and all other responses as 'new'. The more categories are considered as 'old' responses, the more liberal the bias. The form of the resulting function (curve) can inform something about the properties of the underlying processes. When a threshold process is assumed, there is a certain probability of a hit for very high confident judgments. However, as signal strength is not assumed to vary much above threshold, true memory with lower confidence is not expected. Due to low confidence guessing, hit and FA rates increase simultaneously resulting in a linear ROC curve (Figure 1.1.D). When a signal-detection process is assumed, hit rates increase faster than FA rates at the 'high confidence old' end. At the other end ('new' responses) FA rates increase faster than hit rates. Due to the Gaussian memory strength distributions the curve is symmetrical (Figure 1.1.C). Thus, pure recollection-based responding would result in a linear ROC curve, whereas pure familiarity-based responding would yield a perfectly symmetrical curve over the diagonal. Recognition memory as proposed by dual-process models results in skewed ROC curves which incorporate a linear and a symmetrical component (Figure 1.1.E) (Yonelinas, 1994). Thus, by estimating the proportion of each component, parameter estimates for familiarity (the degree of curvilinearity) and recollection (the intercept) can be derived. One critical issue is that reliable estimates can only be obtained with a relatively large number of responses for each class of stimuli (Yonelinas & Parks, 2007). Moreover, in order to base conclusions on the parameter estimates it is necessary to ensure that other models (assuming different parameters) do not better fit the data.

The Remember/Know Procedure

Using the remember/know (R/K) procedure (Tulving, 1985), participants are asked to subjectively judge whether they remember (R) any study details or they just know (K) that the item has occurred in the study phase without having explicit memory for the study episode. The probability of recollection equals simply the probability of a correct 're-member' response to an old item. However, it is assumed that familiarity and recollection while being independent can occur concurrently. Therefore, the fact that participants can only respond 'know' when they have not recollected leads to an underestimation of familiarity when equaling it to the probability of a 'know' response. Thus, this number has to be qualified by the total number of items for which no recollection has occurred ($P(F) = P(K)/(1 - R)$) (Yonelinas & Jacoby, 1995). In some applications, the procedure allows also for a 'guess' response in order to avoid that guessing artificially increases the 'know' response rate (Gardiner, Ramponi, & Richardson-Klavehn, 1998). When applying the R/K procedure, it is essential that participants have perfectly understood the difference between the two response options as this method completely relies on the subjective judgments of the participants. However, it can be assumed relatively – although surely not completely – process pure (Migo, Mayes, & Montaldi, 2012).

Source Memory Tasks

Source memory tasks tap into the unique ability of recollection to retrieve details from the study episode. In a classic example, participants study items presented on different background colors constituting the study sources. Old and new test items are presented without background color. In a two-step procedure, participants have to make an old/new judgment and if they respond 'old', they have to indicate on which background the item was presented during the study phase. It is assumed that correct source judgments can only be based on recollection whereas correct old/new judgments followed by an incorrect source judgment rely on familiarity without recollection.

Although source memory has the advantage that the participants' task is straightforward and is not subject to individually different task interpretations, it also has its caveats (as listed by J. R. Taylor & Henson, 2012). One problem which arises when only a small number of sources or response options are used (e.g., a blue and a red background) is guessing. In the example case, a correct source judgment has a 50 percent probability even without any recollection. On the other side, an incorrect source judgment does not necessarily imply a complete lack of recollection as non-criterial recollection of other study details such as self-generated associations can occur (Yonelinas & Jacoby, 1996). Moreover, if source and stimulus are encoded in a unitized manner, the source might be correctly remembered because the arrangement of item and source is familiar as a whole (Diana, Yonelinas, & Ranganath, 2008; Staresina & Davachi, 2008). This latter issue is discussed in more detail in chapter 2.3.

Response-Deadline Procedure

As already described above, familiarity signals are assumed to be available earlier than those of recollection. Thus, if participants are forced to respond in a very limited time, it can be assumed that responses rely primarily on familiarity. Evidence comes from studies showing that performance in tasks relying more on familiarity is better than in tasks requiring recollection when responses have to be given under time pressure (e.g., Gronlund & Ratcliff, 1989; Hintzman & Curran, 1994). Although no parameter estimates can be derived from the response-deadline procedure, it is a quite strong method to investigate familiarity as it does not require any subjective judgments and the likelihood of a contamination by recollection is relatively small (e.g., Mecklinger, Brunnemann, & Kipp, 2010). A related method is the familiarity-only instruction, where subjects are trained to distinguish between familiarity and recollection similar to the remember/know procedure but are instructed to avoid rec-

Box 1.1: ***Lesion studies and imaging methods***

In order two understand the cognitive processes happening in human brains, neuroscience methods have proved to be inevitable. The three methods which are relevant to this thesis are briefly summarized in this box. The reasoning in classical neuropsychology relied for a very long time mainly on lesion studies. The rationale behind them is to show that a patient who suffers from a lesion in a specific brain region is unable to perform a specific cognitive function in order to link the brain region to the function. To date, lesion studies are still the only means to draw causal inferences about locations of functions. It has to be kept in mind, however, that lesions can also lead to re-organization in the intact part of the brain. When investigating healthy subjects, one can capitalize on the circumstance that electrical activity in the brain is still measurable at the surface of the head. By means of electrodes placed on someone's scalp continuous electroencephalogram (EEG) can be recorded. The EEG is measured as a voltage difference between two electrodes reflecting the sum of all electrical activity on these specific locations on the head surface. Event-related potentials (ERPs) can be extracted when several signals are averaged time-locked to a specific class of stimuli whereby specific activity is isolated from the unspecific random activity. An ERP is characterized by its positive and negative peaks which can be linked to different cognitive functions. ERPs are the only means of real-time measuring cognitive processes albeit with a relatively coarse spatial resolution. A higher spatial resolution (normally 2-3 mm^3) can be obtained by functional magnetic resonance imaging (fMRI) which can identify regions which are more activated in one condition compared to another condition. Magnetic resonance (MR) signals emerge from the radiation emission of hydrogen nuclei. Activation is indicated by different blood-oxygen-level-dependent MR signals. This is based on the rationale that brain activation leads to an increased demand for blood supply and thus for more oxygen which alters the MR signal.

ollection. Trials for which participants report unintentional recollection are excluded from analysis (e.g., Migo, Montaldi, Norman, Quamme, & Mayes, 2009). This method rests more on participants' understanding and compliance than the response-deadline procedure but allows greater inter-individual variance in general processing speed.

1.2.3 Assessment of Familiarity and Recollection by Event-Related-Potentials

Adding to the behavioral methods described above, one of the most compelling evidence that familiarity and recollection are two separable processes in the brain comes from event-related-potential (ERP, see Box 1.1 for basic information about methods in cognitive neuroscience) research (Donaldson & Curran, 2007). In recognition memory tests, hits generally elicit more positive-going waveforms than correct rejections which is labeled the ERP old/new effect. Familiarity and recollection are associ-

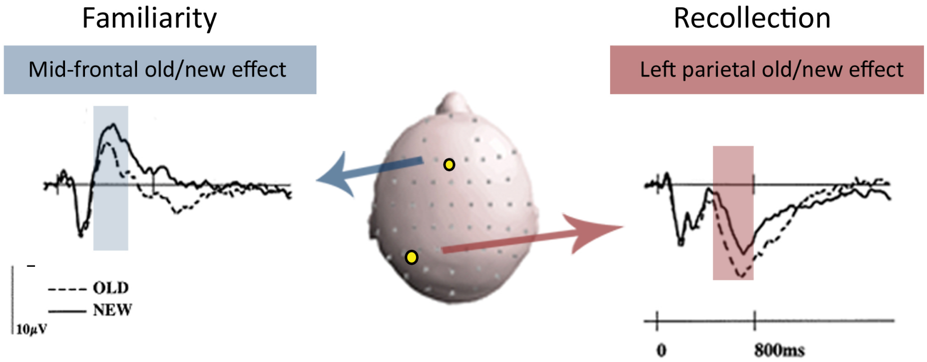


Figure 1.2.: ERP old/new effects. Hits typically elicit more positive going waveforms than FAs. In the middle, the scalp locations are indicated where the effects are usually maximal. Familiarity is associated with the mid-frontal old/new effect occurring 300-500 ms after stimulus onset. Recollection is associated with the left parietal old/new effect occurring in a later time window between 500 and 800 ms.

ated with two different ERP old/new effects (Mecklinger, 2000; Rugg & Curran, 2007). Importantly, the two ERP old/new effects were shown to occur independently of each other (Jäger, Mecklinger, & Kipp, 2006). Familiarity is associated with the mid-frontal old/new effect which is maximal over bilateral frontal electrode sites and occurs between 300 and 500 ms after stimulus onset. The putative ERP correlate of recollection is the left parietal old/new effect which occurs 500 to 800 ms after stimulus onset and has a left-lateralized posterior distribution (see Figure 1.2).

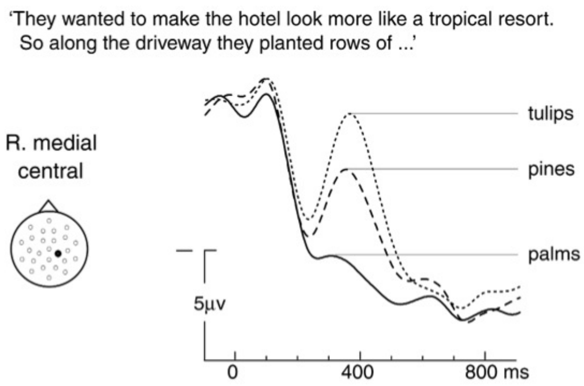
An impressive number of studies has shown that experimental manipulations affect the two effects in a way that parallels the outcomes for behavioral measures of familiarity and recollection. The left parietal effect was shown to be larger for items encoded in a deep semantic encoding condition compared to a shallow encoding condition in line with the assumption that deep encoding can accumulate more study details which can subsequently be retrieved (Rugg et al., 1998). In a source retrieval task, Wilding and Rugg (1996) demonstrated that the left parietal effect was larger for items for which the source was remembered correctly in contrast to when it was not remembered correctly. In a similar vein, the effect is sensitive to the amount of recollected information. The more study details are remembered during retrieval, the larger is the associated left parietal effect (Vilberg, Moosavi, & Rugg, 2006). Moreover, reports of R responses in R/K paradigms are associated with a greater positivity than reports of high confident K responses (Woodruff, Hayama, & Rugg, 2006; Yu & Rugg, 2010). In line with recollection being relatively slowly available, the left parietal effect is attenuated by imposing a response deadline on a recognition test (Mecklinger et al., 2010).

In contrast, the mid-frontal old/new effect is not influenced by the aforementioned variations of memory for study details (Rugg et al., 1998; Vilberg et al., 2006; Wilding & Rugg, 1996) nor by response deadline manipulations (Mecklinger et al., 2010). Furthermore, it is comparable in size for hits and FAs to similar new items (e.g., rat vs. rats) which is in line with the notion that familiarity is not influenced by specifics from the study episode but is rather sensitive to the gist (Curran, 2000). Moreover, the mid-frontal effect is not larger for R responses than high confident K responses and varies with familiarity strength as indicated by confidence judgments (Woodruff et al., 2006; Yu & Rugg, 2010). Moreover, the mid-frontal old/new effect was dissociated from ERP correlates of implicit memory (e.g., Rugg et al., 1998).

Although the mid-frontal effect is consistently and exclusively observed in recognition memory studies and behaves as one would expect, the notion that it is a process-pure ERP correlate of familiarity was challenged by the claim that it reflects conceptual priming, i.e. facilitated conceptual processing for studied vs. unstudied items (see Paller, Voss, & Boehm, 2007). One of the core arguments brought up in favor of this view is that there seems to be no mid-frontal effect whenever the to-be-remembered stimuli lack meaning such as in the case of kaleidoscope images (Voss & Paller, 2009). For extremely rare words with unknown meanings and line drawings of non-objects, it was shown that the mid-frontal effect only occurs for items which are subjectively perceived as meaningful (Voss, Schendan, & Paller, 2010; Voss, Lucas, & Paller, 2010). Moreover, Voss and Federmeier (2010) claimed that the mid-frontal old/new effect is indistinguishable from another ERP component, the N400 (see Box 1.2), which is associated with semantic processing, when they are compared within one experiment. However, the latter finding was recently refuted in a study where a semantic priming paradigm and a recognition memory task were separated more clearly resulting in significantly different scalp distributions of the corresponding ERP effects (Bridger, Bader, Kriukova, Unger, & Mecklinger, 2012). The findings that meaningless stimuli do not elicit a mid-frontal effect are not necessarily at odds with a familiarity account as it is possible that familiarity and conceptual priming have overlapping neural generators (see Bridger et al., 2012, for full argu-

Box 1.2: ***The N400 - A neural marker of semantic integration***

The N400 is an ERP component with a negative deflection between 200 and 600 ms after stimulus onset. Typically, it has a slightly right centro-parietal distribution over the scalp although this may vary depending on the stimulus materials (Kutas & Federmeier, 2000, 2011). The N400 was discovered by Kutas and Hillyard (1980) who showed that the negative deflection was larger for incongruent compared to congruent sentence endings (e.g., He shaved off his mustache and city.). In the meantime, changes in the magnitude of the N400 have been observed with numerous semantic manipulations such as fit within different kinds of context, semantic priming, and semantic category membership. Moreover, it occurs automatically without any specific task demands. The N400 effect refers to the difference between the amplitudes in two conditions. The figure shows that implausible words within a specific context elicit a larger N400 than plausible ones, but that this effect can be reduced if the implausible word belongs to the expected category. Although the exact nature of underlying processes is still under debate, the N400 is generally assumed to signal ease of semantic processing. Greater ease is reflected by smaller amplitudes (Kutas & Federmeier, 2000, 2011). The discussion of the neural generators is also still on-going with a network of contributing brain areas being most likely. This network probably includes the inferior frontal gyrus, the anterior temporal lobe, the angular gyrus and the posterior middle temporal gyrus (Lau, Phillips, & Poeppel, 2008). The figure is reproduced from Kutas and Federmeier (2000, p. 466) with permission from Elsevier.



ment) and that meaningfulness is a prerequisite for familiarity to occur. However, as the findings by Bridger et al. clearly demonstrate (see also Greve, Rossum, & Donaldson, 2007; Küper, Groh-Bordin, Zimmer, & Ecker, 2012), there must also be components specific to familiarity. This might be the act of relating the current processing experience to an event in the past (Hayes & Verfaellie, 2012).

On the one hand, ERPs provide unequivocal support for the existence of two independent processes contributing to recognition memory. On the other hand, given that conceptual priming can be ruled out as a confound, the mid-frontal and the left parietal old/new effect can now serve as independent online measures of familiarity and recollection, respectively, without need for specific response requirements. In the following section, I turn to the assumed neural grounding of familiarity and recollection.

1.3 Neural Grounding of Recognition Memory

Models on the neural basis of recognition memory predominantly center around the role of the medial temporal lobes (MTL). Accordingly, this chapter starts with models focusing on the MTL alongside relevant neuropsychological and functional magnetic resonance (fMRI) findings (see Box 1.1). Thereafter, I turn to other regions distributed over the whole brain which are specifically or generally linked to familiarity and recollection.

1.3.1 Recognition Memory and the MTL

Models of the MTL Memory System

The MTL memory system is often described in a hierarchical manner with the hippocampus heading the system. It receives input mainly from the underlying neocortical areas within the MTL (see Figure 1.3). Infor-

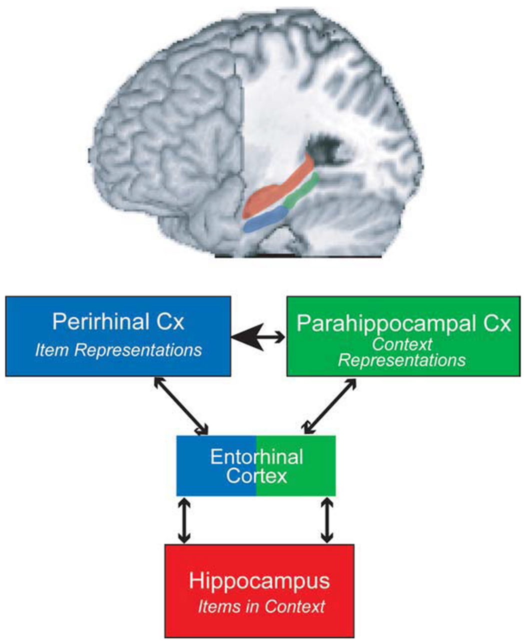


Figure 1.3.: The medial temporal lobe memory system. Indicated are the locations of the perirhinal, parahippocampal, and entorhinal (extending medially along perirhinal and parahippocampal cortex) cortex, as well as the hippocampus. Flow chart depicts specificity of the different regions with regard to the stored representations as suggested by the BIC model. Arrows imply direction and amount of information flow. This figure is reproduced from Ranganath (2010, p. 1265) with permission from John Wiley & Sons, Inc.

mation flows from uni- and polymodal association areas to the perirhinal (PrC) and parahippocampal cortices (PhC) which correspond to the anterior and posterior part of the parahippocampal gyrus. From there it is passed on via the entorhinal cortex (EC) to the hippocampus (e.g., Squire, Stark, & Clark, 2004). The single-process view on the MTL memory system postulates that an episodic memory judgment is based on one single memory signal. Thereby evidence is accumulated in the hippocampus which receives and relates input from different sources (Squire et al., 2007). Activity variations in the parahippocampal gyrus as well as the hippocampus are assumed to be predictive of variations in familiarity and recollection (Kirwan et al., 2008; Wixted & Squire, 2011). However, according to the dual-process view of the MTL memory system, there is a division of labor between the structures of the MTL. The hippocampus proper is thought to be essential for the binding of separable parts of an event and is thus the core structure of the neural network subserving recollection. Conversely, the parahippocampal gyrus can only deal with representations which are non-relational in nature (Aggleton & Brown, 2006; Diana, Yonelinas, & Ranganath, 2007; Henke, 2010; Montaldi & Mayes, 2010; Opitz, 2010b; Ranganath, 2010; Mayes, Montaldi, & Migo, 2007; Yonelinas et al., 2010). Whereas all these models converge on the aforementioned general notions, there are also differences between the proposed frameworks. Most of the models assume that the PrC signals familiarity for an item. However, only the binding-of-item-and-context (BIC) model specifies a particular role for the PhC. It predicts that the PhC deals with representations of contexts and is therefore more involved in recollection (Diana et al., 2007; Ranganath, 2010). The BIC model views recognition memory generally as an episodic task and thus familiarity and recollection are regarded as episodic processes. In contrast, Aggleton and Brown (2006) clearly limit episodic memory functions to the hippocampus. Only recollection is thought to be mediated by this episodic system because contextual details are one of the defining properties of episodic memory. Familiarity arising in the parahippocampal gyrus subserves recognition memory in a non-episodic manner (see also Aggleton, 2012). The models proposed by Henke (2010) and Opitz (2010b) are more general in the sense that they extend the principal of a representational parahippocampal gyrus and a relational hippocampus to unconscious memory or other cognitive domains such as language, respectively.

Whereas the models described above make predictions about the mapping of familiarity and recollection to brain regions, Norman and O'Reilly (Norman & O'Reilly, 2003; Norman, 2010; O'Reilly & Norman, 2002) outline the computational principles underlying the two processes. This model is based on the complementary-learning-systems (CLS) approach proposed by McClelland, McNaughton, and O'Reilly (1995). The CLS assumes one learning system (the neocortex) which extracts regularities from incoming information (Where is the best butcher's shop in town?) at a rather slow learning rate. Another learning system (the hippocampus) is assumed for quick learning of specifics (Where did I buy this yummy steak last week?). In the hippocampal system, during learning the input layer of EC projects incoming information to region CA3 (cornus ammonis region 3) of the hippocampus (directly and indirectly via the dentate gyrus), where pattern-separated, i.e. mostly non-overlapping, representations are assigned to different elements of the input. This is possible because only a few units are active for each representation. The representations are connected to each other by Hebbian learning which results in an episodic trace. This ensemble in turn is re-represented in region CA1 which has connections back to the output layer of EC. This loop provides the possibility that a partial cue of the study episode reactivates the whole episodic trace in CA3 and the missing part of the episode can be re-instantiated in the output layer of EC via CA1. In the context of recognition memory, the hippocampal system is well suited to mediate recollection. In the neocortical model, novel items lead to a rather weak activation of a larger number of units in the MTL cortices (MTLC). With repeating presentations, the activation pattern becomes sharper through Hebbian learning and inhibitory competition, i.e. in the end only a selected set of units is strongly activated. In contrast to the hippocampal model, similar inputs lead to overlapping representations. Therefore, small details may not be sufficient to discriminate between two items. Moreover, for strong and distinct familiarity signals multiple repetitions are needed. The CLS framework provides an anatomically plausible description of the computational principles of recognition memory from which novel predictions can be derived and independently tested (e.g., Migo et al., 2009).

Neuropsychological and fMRI Evidence for the MTL Memory System

In support of the models sketched in the preceding paragraph, patients with circumscribed hippocampal lesions (HC-patients) show a selective deficit in recollection accompanied by spared familiarity. For instance, several studies have revealed greater problems for HC-patients in recall tasks than in item recognition (Baddeley, Vargha-Khadem, & Mishkin, 2001; Holdstock, Mayes, Gong, Roberts, & Kapur, 2005; Yonelinas et al., 2002). While recall tasks are assumed to rely primarily on recollection (Baddeley et al., 2001), item recognition can be based on an intact familiarity partly compensating for the recollection deficit. Additionally, comparing HC-patients to patients with lesions affecting the hippocampus plus the underlying cortices (MTL-patients) as well as to healthy controls, Yonelinas et al. (2002) showed that parameter estimates of recollection derived by two different methods (R/K and ROCs) were smaller for both patient groups compared to the controls. However, familiarity estimates were only reduced for the MTL-group whereas the HC-group exhibited normal familiarity levels. Moreover, in a single case study, Holdstock et al. (2005) found a greater impairment in 'remember' responses than in 'know' responses in a patient with a circumscribed hippocampal lesion (but see Manns, Hopkins, Reed, Kitchener, & Squire, 2003). This is in line with the notion that the hippocampus is essential for recollection but not familiarity. Further support comes from two ERP studies showing an elimination of the left parietal old/new effect in HC-patients who at the same time exhibit a normal mid-frontal old/new effect (Addante, Ranganath, Olichney, & Yonelinas, 2012; Düzel, Vargha-Khadem, Heinze, & Mishkin, 2001). However, an important piece in the neuropsychological picture of two independent processes in recognition memory is the complementary finding that lesion to the parahippocampal gyrus harms familiarity but leaves recollection intact. Bowles et al. (2007) provided this piece of evidence by examining the memory performance of patient N.B. whose left PrC and EC were largely resected. N.B. showed normal levels of recollection whereas familiarity estimates obtained in R/K and ROC paradigms were considerably lower than those of the controls. Moreover, under speeded response conditions she performed significantly worse than the controls. Taken together, neuropsychological evidence suggests that familiarity and recollection operate independently from each other in separated brain regions within the MTL.

fMRI studies provide a valuable complementary means to neuropsychological studies as they tell us about memory function in healthy brains. In the following brief review, I focus only on studies examining the retrieval phase in recognition tasks. Combining fMRI with the R/K method, the evidence consistently suggests that R responses are accompanied by stronger activation in the hippocampus than K responses (Eldridge, Knowlton, Furmanski, Bookheimer, & Engel, 2000; Montaldi, Spencer, Roberts, & Mayes, 2006; Yonelinas, Otten, Shaw, & Rugg, 2005). Activation modulation in the PrC is not always observed, however, one study showed that increasing levels of K confidence are associated with a linear decrease of activation in the PrC (Montaldi et al., 2006). Moreover, Henson, Cansino, Herron, Robb, and Rugg (2003) summarized the findings from four independent experiments which showed that activation in the PrC is reduced for hits compared to CRs irrespective of memory for contextual details. This is in line with a sharpening process in the PrC where activation for novel stimuli is diffuse and a second presentation of an item leads to stronger activation, but in considerably less units. This results in a lower net activity. A comparable deactivation pattern was shown to be insensitive to depth of encoding implicating that it is not influenced by recollection (Henson, Hornberger, & Rugg, 2005). Another way to extract process-specific activation is modeling the fMRI signal with a function of confidence judgments (1 - 6). For recollection the function is flat for 1 to 5 and sharply increases from 5 to 6 in line with a high threshold process whereas for familiarity the function linearly increases or decreases from 1 to 5 and levels out from 5 to 6. Applying this rationale, Daselaar, Fleck, and Cabeza (2006) showed that activation in the hippocampus follows the recollection function, whereas activation in the PrC is best modeled by a decreasing familiarity function. Summing up the fMRI findings, hippocampal activation increases during recollection-based recognition whilst when modulation of activation in the PrC is observed during recognition memory it is mostly an activation decrease which is associated with enhanced familiarity.

1.3.2 Recognition Memory Outside the MTL

With the advent of fMRI the conception of which role other brain regions outside the MTL play in recognition memory has moved closer to the center of interest. Evidence from lesion studies is rare probably because deficits due to the mostly unilateral lesions can be compensated for by the contra-lateral hemisphere (Vilberg & Rugg, 2008). First of all, old/new effects (activation differences between hits and CRs) can be found all over the brain. However, only some of them can probably be linked to specific memory processes. Others might rather be implicated in general control processes. Yet, there have been attempts to localize activation specifically related to familiarity and recollection all over the brain, the general implication being that it is the lateral and medial surfaces of the prefrontal (PFC) and the parietal cortex (but also lateral temporal lobe) which are mostly involved in the two processes (see for example Figure 1.4). Old/new effects are very consistently found in the posterior parietal cortex (PPC) and different sub-regions of the PPC have been associated with different aspects of recognition memory (for reviews see Nelson et al., 2010; Vilberg & Rugg, 2008; Wagner, Shannon, Kahn, & Buckner, 2005). Activation in the ventro-lateral PPC seems to be associated with recollection. For instance, activation in these regions is sensitive to the depth of processing during study (Henson et al., 2005), higher for R than high confident K responses (Eldridge et al., 2000; Henson, Rugg, Shallice, Josephs, & Dolan, 1999; Wheeler & Buckner, 2004; Yonelinas et al., 2005), related to the amount of recollected information (Vilberg &

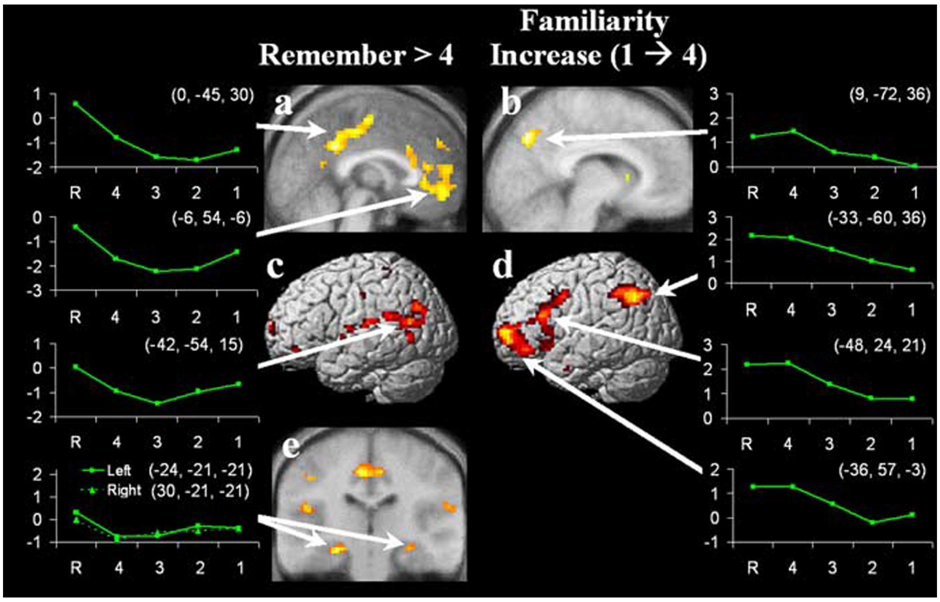


Figure 1.4.: fMRI correlates of familiarity and recollection. Regions following the recollection function (a, c, e) and regions following the familiarity function (b, d) in the study by Yonelinas et al. (2005). Parameter estimates as a function of response type are shown for peak voxels of each region. This figure is reproduced from Yonelinas et al. (2005, p. 3005) with permission from the Society of Neuroscience.

Rugg, 2007), follows the oldness function of recollection (Daselaar, Fleck, & Cabeza, 2006), and does not vary with the old/new ratio (Vilberg & Rugg, 2008). The latter point refers to the issue that some old/new effects seem to be related rather to the perceived targetness (the targets are usually the old items which changes with varying old/new ratio) than to memory status per se. The function of the ventro-lateral PPC might be that of a module which directs attention to the recollected information. Moreover, it is proposed to be one of the neural generators of the left parietal old/new effect (Vilberg & Rugg, 2008). A region more superior and medial to the recollection-related PPC region in the vicinity of the intra-parietal sulcus was related to familiarity-based memory because it shows greater activation for hits than CRs irrespective of depth of encoding (Henson et al., 2005), activation increases with increasing confidence but is not greater for R than high confidence K judgments (Yonelinas et al., 2005) and follows the familiarity oldness function (Daselaar, Fleck, & Cabeza, 2006). However, it has not always been exclusively activated only for familiarity (e.g., Wheeler & Buckner, 2004) and seems to be associated with targetness (Herron, Henson, & Rugg, 2004; Vilberg & Rugg, 2008).

Old/new effects have also been observed on the medial surface of the parietal cortex for both recollection and familiarity whereby a dissociation for different regions according to the different processes is less obvious than in the lateral PPC. However, the posterior cingulate and the retrosplenial cortex were associated with recollection (Daselaar, Fleck, & Cabeza, 2006; Yonelinas et al., 2005; but see Montaldi et al., 2006) and were postulated to be part of the extended hippocampal system of episodic memory (Aggleton & Brown, 2006). More posterior parts like precuneus and cuneus were more often associated with familiarity (Daselaar, Fleck, & Cabeza, 2006; Yonelinas et al., 2005). Activations in the PFC are typically related to top-down control on memory (Simons & Spiers, 2003) which is why they have traditionally been linked to recollection which demands more strategic involvement. Lateral PFC activation was observed for R judgments (Eldridge et al., 2000) and follows the recollection function (Daselaar, Fleck, & Cabeza, 2006). However, other evidence suggests that lateral PFC follows the familiarity function (Montaldi et al., 2006; Yonelinas et al., 2005). Moreover, a recent study showed that lateral PFC lesions lead to a selective impairment of familiarity (Aly, Yonelinas, Kishiyama, & Knight, 2011). Findings regarding the involvement of the medial PFC are also mixed and might be related to control processes common to familiarity and recollection (Montaldi et al., 2006; Yonelinas et al., 2005). A clear dissociation of the sub-regions of the lateral and medial PFC has still to be determined (for a detailed discussion of differential PFC contributions to familiarity and recollection see Aly et al., 2011).

After this overview on recognition memory and its underlying processes, the chapter closes with a short discussion on the relationship of recognition memory to the semantic and episodic memory systems.

1.4 Relating Recognition Memory to the Semantic and Episodic Memory Systems

Episodic and semantic memory are regarded as two separable memory systems in the brain (e.g., Tulving, 1985). Accordingly, semantic dementia implicates deficits in classical semantic neuropsychological tasks such as category fluency but spares episodic recall (e.g., Davies, Graham, Xuereb, Williams, & Hodges, 2004). In contrast, circumscribed hippocampal lesions dramatically affect episodic memory but do not preclude new semantic learning (Baddeley et al., 2001; Vargha-Khadem et al., 1997; Verfaellie, Koseff, & Alexander, 2000). However, both systems are highly interacting. For example, much semantic content is presumably initially encoded as episodic information (Moscovitch et al., 2006) which is probably why hippocampal patients' semantic learning occurs at a lower rate and much slower than in healthy controls (Baddeley et al., 2001; Verfaellie et al., 2000; but see Tulving & Markowitsch, 1998, for the view that episodic memory always implies semantic memory).

Generally speaking, recognition memory is a form of explicit memory (although there might also be influences from implicit memory) and can be related to semantic and episodic memory. Frequently, recognition memory is characterized as an expression of episodic memory (e.g., Davachi & Wagner, 2002; Greve, Donaldson, & Rossum, 2010). Others, however, stress that recognition memory can involve episodic memory but is not subsumed by it (e.g., Aggleton & Brown, 2006). Moreover, there is also evidence for the impact of semantic memory on recognition memory (e.g., Greve et al., 2007; Opitz & Cornell, 2006).

The best way of looking at recognition memory is probably to acknowledge that the semantic and episodic system can both be involved and the degree of involvement of one or the other is strongly moderated by the exact nature of the recognition task. For instance, meeting a person on the street always prompts one to make a recognition decision and one can reach this decision by recruiting one or the other or both systems. First, if you can immediately tell that this person is your friend's sister, you recognized this person by accessing your semantic memory. Second, you might remember that you have once been to the cinema together which triggered the memory that your friend was also there. This in turn triggered the memory that your friend told you that she was his sister. In this case, your episodic memory told you that you have seen this person before. Third, it might be a mixture of both. For example, you immediately have to think of your friend because he is connected to her in your semantic memory, but your episodic memory tells you what your friend told you who she was. Hence, whenever recognition memory is investigated in the laboratory, it is important to be clear about which memory system is addressed. By this, the respective contributions of familiarity and recollection might vary accordingly as the two processes have been associated with the two systems in different ways.

Being per definition episodic in nature, the question is rather uncontroversial for recollection as hippocampal lesions impair autobiographic episodic memory and recollection (see Aggleton & Brown, 2006, for a review). Moreover, remembering autobiographic episodes and recollection activate common brain regions (Cabeza et al., 2004). How to relate familiarity to the two memory systems is more controversial. However, research in recent years strongly suggests an important role of the semantic system in familiarity-based recognition memory. For instance, the mid-frontal old/new effect was shown to be modulated by semantic manipulations. Opitz and Cornell (2006) found an enhancement of the mid-frontal old/new effect for words which were previously encoded in an associative context (Which one of four words does not fit in the context?: e.g., oasis – camel – chair – desert) in contrast to a size relational context where an early mid-frontal effect seemed to be absent. Integration into a semantic context enhanced the mid-frontal effect also in another study where corresponding category labels were provided for word pairs (e.g., animal: rabbit – mouse) during an associative recognition task (Greve et al., 2007). Interestingly, in both studies the left parietal old/new effect was unaffected by the semantic manipulation. Moreover, greater semantic integration efforts during study (enlarged N400) are correlated with enhanced familiarity during later testing (increased mid-frontal old/new effect) but not with stronger recollection (Meyer, Mecklinger, & Friederici, 2007; for a related finding with behavioral methods see Wang & Yonelinas, 2012). Thus, since relating study stimuli to existing semantic knowledge can enhance familiarity-based decisions in recognition memory, a connection between familiarity and semantic memory stands to reason. Moreover, the similarity in topographical distribution and timing of the N400 and the mid-frontal old/new effect suggests at least overlapping neural generators which is evident in the controversial discussion about the contamination of the mid-frontal old/new effect by conceptual processing (Bridger et al., 2012; Paller et al., 2007; Voss & Federmeier, 2010, see also Section 1.2.3). A possible candidate for a double contribution to semantic processing and familiarity-based memory is the anterior medial temporal lobe including the PrC. As already described in detail in section 1.3.1, the PrC seems to be crucial for familiarity-based remembering (Bowles et al., 2007; Montaldi et al., 2006). It has, however, also been implicated in semantic tasks. For example, patients with semantic dementia who have severe problems in semantic categorization suffer from damage to the anterior medial temporal lobe (e.g., Davies et al., 2004). Moreover, a patient group with maximal lesion overlap in a region within the PrC showed significantly reduced implicit conceptual memory in two different tasks (exemplar generation and a semantic decision task). In addition, activity levels in the very same region in healthy participants predicted subsequent behavioral conceptual priming effects (Wang, Lazzara, Ranganath, Knight, & Yonelinas, 2010). Meyer, Mecklinger, and Friederici (2010) established a connection between the PrC involvement during semantic processing and familiarity-based recognition. They showed that enhanced semantic processing during study is accompanied by increased activation in the anterior MTL and subsequently leads to a greater familiarity-related reduction of activation in an overlapping region. Although it is yet unclear how large the overlap is between familiarity and the semantic system, there is strong evidence that semantic memory plays a crucial role in familiarity-based recognition.

This becomes even more evident in the next chapter on associative recognition memory where semantic integration turns out to be one of the key factors if familiarity contributes to recognition memory in the first place.

CHAPTER 2

Associative Recognition Memory

One of our main memory tasks is to store and retrieve associations between different pieces of information such as somebody's face and the occasion where we met that person. Thus, the ability to remember associations is essential for episodic remembering. One way to investigate this ability is the associative recognition memory paradigm in which participants have to recognize that they have encountered a specific association or combination of items in the study phase. Essential to this paradigm is that participants have to discriminate between pairs reappearing in the same pairing as during prior study and new combinations of studied items, i.e. recombined pairs. Both types of pairs comprise constituents that were previously encountered and thus are equally familiar. Therefore, they can only be discriminated from each other on the basis of associative information.

2.1 Types of Associations

In order to gain a comprehensive picture of the processes involved in memory for associations, clear definitions of the different types of associations are a prerequisite. Mayes et al. (2007) carefully describe a classification system which is widely accepted. The broadest distinction is made between inter-item and intra-item associations. Inter-item associations are associations between at least two separate items such as the word pair *tree-dog*. Within this category, Mayes and colleagues distinguish between within-domain and between-domain associations. The former refer to pairs or groups of items belonging to the same domain whereas the latter refer to pairs or groups of items from different domains. Two items belong to the same domain if they "are likely to be represented by activity in closely adjacent and interacting neocortical neurons" (Mayes et al., 2007, p. 126), i.e. have overlapping representations. The examples provided include word-word and face-face pairs. Intra-item associations fit into an entity-defining framework (Mecklinger & Jäger, 2009) or a given template (Mayes et al., 2007). For instance, the different components of a face (eyes, nose, etc.) are perceived and encoded within a face template. In other words, intra-item associations are associations between components of one single whole, i.e. the components form a unit. Therefore intra-item associations can also be labeled unitized associations. The term unitized association is effectively more general as it can be applied more intuitively to novel units which are formed from previously separate items (e.g., novel compound words). Units feature emergent properties, i.e. properties which cannot be inferred by summing up the properties of their constituents. For instance, the degree of symmetry of a face that cannot be deduced from the properties of the single face parts (Ceraso, 1985; Graf & Schacter, 1989). Moreover, the exact configuration is an important characteristic of units (Horowitz & Prytulak, 1969). In summary, three different kinds of associations are distinguished: between-domain inter-item associations, within-domain inter-item associations, and intra-item or unitized associations.

Although the system described by Mayes et al. (2007) seems to be a functional framework for the description of different types of associations, the problem that objective criteria to categorize associations are missing is yet unresolved. As Mayes and colleagues state themselves, it is hard to say when unitization has occurred, but measurable negative effects on the constituents might be an objective criterion for unitization. In order to mitigate this problem, a reasonable proposition by Yonelinas et al. (2010) suggests that unitization should be regarded as a continuum rather than a dichotomy, i.e. different conditions are differentially likely to lead to a unitized representation of an association. Thus, it is always important to contrast two conditions one of which makes unitization more and the other one less likely. The objection of subjectivity, however, remains. A similar problem holds for the within- and between-domain distinction. For example, the word pair *cup-democracy* consists of two words (same domain) but these two words denote a concrete and an abstract concept, for which overlapping representations seem unlikely.

In addition to the terminology described by Mayes et al. (2007), the term 'arbitrary associations' is used frequently. 'Arbitrary' means that an association was formed more or less randomly and was not predetermined by already existing links. For example, the word pair *tree-computer* constitutes an arbitrary pairing whereas the frequent joint occurrence of desks and computers makes the pair *desk-computer* a non-arbitrary association. According to the common usage of the term, only inter-item associations can be arbitrary because as soon as an association is integrated into a single whole it is not arbitrary anymore. Arbitrary associations, as probably most inter-item associations, are considered to be flexible, i.e. the exact configuration of the association is irrelevant (e.g., *desk-computer* and *computer-desk* are treated similarly by our memory).

2.2 Arbitrary Associations

According to traditional dual-process models of recognition memory (Yonelinas, 2002), recollection is required to retrieve the link between distinct items, whereas familiarity is sufficient in order to recognize single items. This is especially claimed for arbitrary associations. Evidence for this notion is presented in the following section.

2.2.1 Evidence for a Predominant Role of Recollection

The notion that recollection is essential for associative recognition seems to be so evident from the definition of recollection that the direct comparison between item and associative memory has only rarely been made with behavioral paradigms in healthy participants. However, an increased need for recollection in associative memory tasks was confirmed by the findings of Yonelinas (1997). He showed that in contrast to the curvilinear ROC curves for single word recognition, ROC curves for recognition of word pairs are linear without a quadratic component implicating that a diagnostic familiarity signal is missing in the case of associative memory (for further evidence that associative recognition memory relies on a high-threshold process see Parks & Yonelinas, 2009, but see Mickes, Johnson, & Wixted, 2010, for counter evidence). In line with this, Hockley and Consoli (1999) found that old/recombined discrimination for word pairs is only better than chance when based on R responses but not on K responses. Moreover, one ERP study on word pair recognition revealed a left parietal old/new effect in association with successful recognition of associative information whereas there was no evidence of the putative ERP correlate of familiarity (Donaldson & Rugg, 1998).

Lesion studies have provided compelling evidence for the inevitability of the hippocampus in memory for arbitrary associations implicating the need for recollection. Early studies with amnesic patients, for whom, however, the exact etiology is unclear, already showed that memory for arbitrary associations is severely impaired (e.g., Winocur & Weiskrantz, 1976). Two later studies examined the performance of groups of patients with lesions restricted to the hippocampus and found that associative recognition was disproportionately impaired compared to item recognition for word pairs (Giovanello, Verfaellie, & Keane, 2003), face-face pairs and face-name pairs (Turriziani et al., 2004).

Evidence from fMRI mainly comes from memory encoding studies. Generally, they are consistent with the notion that recollection related regions are especially important for associative memory. The hippocampus was more strongly activated by picture-picture associative encoding than by encoding of a single picture (Achim & Lepage, 2005). Similarly, the hippocampus is more involved when encoding emphasizes the relational nature of the to-be-encoded stimuli in contrast to item-focused encoding (Blumenfeld, Parks, Yonelinas, & Ranganath, 2010; Davachi & Wagner, 2002). Moreover, hippocampal activation was shown to be correlated with subsequent associative memory performance (Park & Rugg, 2011; Davachi & Wagner, 2002), i.e. activation was higher for subsequent hits than for subsequent misses. Importantly, similar results were not obtained for the adjacent MTL cortices for which activation was only predictive of subsequent item memory (Davachi & Wagner, 2002). Beside the hippocampus, other regions implicated in recollection such as the ventral PPC and the posterior cingulate cortex showed subsequent memory effects for arbitrary associations (Achim & Lepage, 2005; Park & Rugg, 2008, 2011). One of the most consistently found regions being especially important for associative encoding, however, is the lateral PFC including the middle and inferior frontal gyri. It shows stronger activation for associative than item encoding (Achim & Lepage, 2005) and when instructions emphasize relational in contrast to item information (Murray & Ranganath, 2007; Blumenfeld et al., 2010). Moreover, this region shows subsequent associative memory effects (Park & Rugg, 2008, 2011; Murray & Ranganath, 2007). Note that regions which are engaged during encoding are not necessarily also involved during retrieval, especially regions outside the MTL.

Retrieval studies for associative recognition are rare, especially those directly comparing same and recombined pairs. One of the few exceptions is the study by Giovanello, Schnyer, and Verfaellie (2004) who compared activation during item and associative retrieval of words and word pairs, respectively. They found stronger activation in the hippocampus, the cingulate gyrus, the inferior PPC and the inferior frontal gyrus (IFG) during associative than item recognition (but see Achim & Lepage, 2005, for contrary results for the hippocampus). Thus, this strongly suggests a predominant role of the recollection network when associative information has to be retrieved from memory. Two later studies which found hippocampal activation in a same/recombined contrast (Ford, Verfaellie, & Giovanello, 2010; Giovanello, Schnyer, & Verfaellie, 2009) reinforced the importance of the hippocampus for recognition of arbitrary word pair associations.

2.2.2 Flexibility of Memory for Arbitrary Associations

As described in section 2.1, one important feature of arbitrary associations constitutes their flexibility in the sense that they are not stored in an exact configuration. Evidence in favor of this notion is described in the following. The question of flexibility has primarily been investigated by cued recall tasks in which one part of the association serves as a cue and the other part has to be recalled from mind. Cued recall is assumed to rely solely on recollective processing and the integrity of the hippocampus (e.g., Baddeley et al., 2001). Therefore, it is often used as an indicator of pure recollection in contrast to item recognition tasks (Yonelinas, 2002).

Due to the flexibility of arbitrary associations, cued recall of pairs (e.g., A B) is assumed to be symmetrical. This means that performance in recall with forward cues (A _) and backward cues (_ B) is highly correlated (Kahana, 2002). Under the assumption that recall predominantly relies on the integrity of the hippocampus, symmetry of recall would be predicted by the CLS (O'Reilly & Norman, 2002). The computational principles proposed for the hippocampus predict that each element of a study episode can serve as a cue in order to re-instantiate the whole memory trace. This hypothesis is corroborated by a study with rats showing that associative memory is symmetrical in intact rats whereas this ability is lost in rats with circumscribed hippocampal lesions (Bunsey & Eichenbaum, 1996). In humans, Giovanello et al. (2009) showed that activation in the anterior hippocampus is independent of the order of the test cue in an associative recognition test. Thus, recollection-based retrieval subserved by the hippocampus seems to be flexible with respect to the order of the test cue.

2.3 Non-Arbitrary Associations

As described in the preceding section, most theories of episodic memory assume that the hippocampus is highly implicated in encoding and retrieving associations and by this recollection is assumed to be essential for associative recognition memory. Moreover, as familiarity is thought to arise only in response to a single item, it is not useful for distinguishing between same and recombined pairings. However, a growing literature suggests that under specific circumstances familiarity can support memory for associations. This is in opposition to models of recognition memory which posit an item-association dichotomy for familiarity and recollection (Aggleton & Brown, 2006) or which postulate the requirement for multiple learning episodes for associations to be recognizable based on familiarity (Norman & O'Reilly, 2003; O'Reilly & Norman, 2002). The following section is intended to give a thorough overview of current theories on and empirical evidence for associative recognition memory based on familiarity.

2.3.1 Familiarity for Associations: Theories

Unitization Hypothesis of Recognition Memory

The unitization hypothesis states that "familiarity is not expected to support associative memory for two distinct items, unless the two items can be unitized or treated as a single larger item (e.g., in the way that a nose, mouth, and eyes can form a face)" (Yonelinas, 2002, p. 447). First postulated by Yonelinas (Yonelinas, Kroll, Dobbins, & Soltani, 1999; Yonelinas, 2002) and then incorporated into the BIC model (Diana et al., 2007; Ranganath, 2010; Yonelinas et al., 2010), it integrates findings of familiarity-based associative memory with the notion that familiarity can only arise for single items whereas recollection is required to remember associations. In accordance with the model of Norman and O'Reilly (2003), Yonelinas and colleagues claimed that the hippocampus, with its ability to link non-overlapping representations, is particularly well suited to establish representations for inter-item associations, whereas the PrC extracts more general representations and thus produces a familiarity signal for single items or unitized associations. In agreement with Mayes et al. (2007), Yonelinas et al. (2010) notice that it is impossible to determine whether a specific individual has processed a specific stimulus as one single whole or as an assembly of several items. Therefore, they see unitization as a continuum rather than a dichotomy, i.e. different conditions are differentially likely to lead to a unitized representation of an association (see Section 2.1). It is important to note that according to their view, unitization is theoretically possible for any kind of associations be it within one domain or between domains.

In a related view, Henke (2010) assigns one processing mode to familiarity and priming which can generally operate on single or unitized items on a one-trial learning basis. In line with Yonelinas and co-workers, she assigns a crucial role in familiarity to the perirhinal cortex. In contrast, rapid encoding of arbitrary and flexible associations requires the hippocampus. Both systems, however, can operate independent of consciousness.

Domain-Dichotomy View

The domain dichotomy (DD) view (Mayes et al., 2007) and its advancement, the Convergence, Recollection, and Familiarity theory (CRAFT Montaldi & Mayes, 2010) are not fundamentally different from the unitization hypothesis as they also postulate a dissociation of hippocampus and PrC according to the ability of remembering inter-item and intra-item (unitized) associations, respectively. Crucially, however, Mayes and colleagues also claimed that overlapping PrC representations of similar items (i.e. within-domain inter-item associations) can result in one global familiarity signal whereas this is not possible for between-domain associations. This is, however, only the case when they are presented without a mediator such as a sentence frame because mediators necessarily lead to the requirement of recollection. Thus, there is one main difference in the predictions which can be derived from the DD/CRAFT model and the unitization hypothesis/BIC model: the DD view predicts familiarity-based memory for non-mediated and non-unitized within-domain inter-item associations (see also Mecklinger, in press, for a comparison of these two models).

2.3.2 Familiarity for Associations: Empirical Evidence

Although many of the studies principally address both theories described above, they can nonetheless be sorted according to their focus on one or the other view. I start with the DD view and will afterwards come back to the unitization hypothesis. Although the question of what exactly means within- and between-domain is still unresolved (see Section 2.1), note that the studies described below considered the type of stimulus material as a domain. This operational definition follows the examples provided by Mayes et al. (2007).

Empirical Evidence Addressing the DD View

The main finding on which the peculiarity of the DD view, namely familiarity for non-unitized within-domain inter-item associations, is empirically grounded is the case of the adult-onset amnesic patient Y.R., who suffered from a relatively circumscribed hippocampal lesion (Mayes et al., 2004). Besides spared item recognition, Y.R.'s performance on associative recognition for intra-item associations (e.g., face parts) as well as for word-word and face-face pairs was not significantly below the control group's mean in contrast to her severely impaired memory for between-domain associations. It should also be mentioned that the three patients with early onset-amnesia investigated by Vargha-Khadem et al. (1997) exhibited a pattern of performance which is comparable to Y.R's performance. However, due to the very early brain damage of these patients, functional reorganization within the brain is much more likely and inferences on functionality in healthy brains are even harder to make than for adult-onset patients. These findings are opposed by the study of Turriziani et al. (2004) who examined a group of six patients including five who also had focal lesions in the hippocampus. These patients exhibited as severe deficits for within-domain associations (face pairs) as for between-domain associations (face-occupation pairs). Thus, neuropsychological data on this question are inconclusive.

The results from a study comparing associative memory of younger and older adults might also be of interest within this context (Bastin & van der Linden, 2006) as aging is known to reduce hippocampal volume while leaving PrC volume relatively unaffected (Raz et al., 2005). In line with the Turriziani et al. (2004) study, Bastin and van der Linden (2006) found a disproportionate decline of associative compared to item memory which was equal in size for the two kinds of inter-item associations.

Evidence from behavioral studies regarding the DD view with healthy young participants is rare. Bastin, van der Linden, Schnakers, Montaldi, and Mayes (2010) employed a familiarity-only instruction during test and found that familiarity estimates for face-face pairs were higher than for face-name pairs. However, Harlow, MacKenzie, and Donaldson (2010) highlighted two problematic issues with this study. First, in order to match item performance in the standard recognition instruction task, pairs in the face-face condition were presented for a longer duration during study. Thus, it is possible that familiarity for face-face pairs increased due to longer study time. Second, the comparison of between-domain and within-domain associations was confounded by stimulus type as there were no name-name pairs in the within-domain condition. It might be that specific characteristics of names contributed to the difference between the conditions. Carefully avoiding this confound in their own study, Harlow and colleagues could not find higher familiarity estimates for within-domain (picture-picture and name-name) than for between-domain (picture-name) pairs, neither when using the familiarity-only procedure nor when using the ROC method.

An fMRI study by Park and Rugg (2011) directly compared subsequent memory effects for word-word, picture-picture and word-picture pairs. During encoding participants had to make a size comparison of the two denoted or depicted concepts. Park and Rugg identified domain-specific in addition to domain-general subsequent memory effects. However, activation within PrC could only be identified with a very liberal threshold and this was not specific to within-domain associations. Worth mentioning here is one other study investigating subsequent associative memory effects for word pairs by Jackson and Schacter (2004) which revealed greater PrC activity for subsequent hits in contrast to subsequent misses. Importantly, Jackson and Schacter asked their subjects to form a mental image of the two objects denoted by the word pair in which the two objects interact with each other. Rhodes and Donaldson (2008b) proposed that interactive imagery is a means to foster unitization. In a similar vein, an ERP study by Speer and Curran (2007) showed a mid-frontal old/new effect for pairs of fractals in a condition which was not intended to promote unitization. However, the fractals were presented next to each other without a gap in-between leading to a physical appearance of one single object. Moreover, such fractals lack a pre-experimental meaning and therefore do not encourage participants to perceive them as separate entities. These two factors render an unintentionally unitization very likely (see Zimmer & Ecker, 2010, for a similar argument). Thus, so far no neuroimaging study could convincingly support the DD view.

Summarizing the results which can speak to the critical aspect of the DD view, the evidence to date suggests that belonging to the same domain is neither a sufficient nor a necessary condition for familiarity-based associative recognition memory to occur. Yet, the critical factors for patient Y.R.'s normal performance on within-domain associations despite her impaired hippocampus have to be determined.

Empirical Evidence Addressing the Unitization Hypothesis

In recent years the number of studies aiming to investigate the role of unitization in associative recognition memory has grown relatively large using a broad range of behavioral, neuropsychological, and neuroimaging methods. The ways of approaching the concept of unitization have also been manifold. However, the discussion about the implications of the results has mainly neglected this diversity. Here, I present the existing literature sorted according to whether unitization was achieved by providing an entity-defining template, by the existence of a pre-experimental relationship between the to-be-associated information, by the integration of item and source information, or by the use of an encoding strategy which combines previously unrelated item-item associations to a single whole. The aim is to integrate all the findings which were derived by using different methods for each of these approaches and to provide an explanation on how unitization might differentially be effective in these approaches.

Unitization by Means of a Given Entity-Defining Frame In a seminal study, Yonelinas et al. (1999) investigated contributions of familiarity and recollection to recognition memory for combinations of single face parts. At test, participants had to discriminate between studied combinations and recombined versions of the studied faces (i.e. the external features such as hair, head shape, ears, and visible clothing of one studied face were recombined with the central features such as eyes, eyebrows, nose, mouth, and facial markings of another studied face). The critical manipulation in this design was that the faces were presented either upright or upside down. As humans are very experienced in processing upright faces as a single whole, upright presentation of a face provides an entity-defining frame whereas a face which is presented upside down lacks this frame and is thus perceived as a collection of discrete face parts. Deriving process estimates from ROC curves, Yonelinas and colleagues revealed that familiarity contributed significantly to recognition memory for upright faces but not for upside down faces. The contribution of recollection, however, was equal for the two conditions. Hence, this study provided the first evidence that familiarity can contribute to associative memory when a collection of items is processed in a holistic manner.

Extending the entity-defining frame from mere faces to entire persons, Jäger et al. (2006) based their study on the rationale that an original and a slightly morphed picture of a face would be perceived as belonging to the same person and therefore as unitized (intra-item). This should naturally not be the case for two pictures of two different persons (inter-item). After studying face pairs, participants had to recognize single faces with a subsequent forced choice test about the study phase partner. As predicted, a mid-frontal old/new effect was elicited for faces from the intra-item condition when the study phase partner was subsequently also correctly recognized but not when this associative information was not retrieved. In contrast, inter-item associations did not elicit a mid-frontal effect. The two studies with facial stimuli strongly suggest that if one can make use of a pre-existing template such as a face or a person to integrate to-be-associated information into one, familiarity supports recognition of these associations.

Unitization of Source Information Memory for source information of an item, i.e. memory for the context during study, does not constitute item-item binding; however, it is associative in the sense that source memory requires binding of item and context. Therefore, it is commonly assumed to rely on recollection. Indeed, the presence or absence of source memory has often been used as an operational definition of recollection (e.g., Ranganath et al., 2003, see section 1.2.2). However, in doing so one needs to make sure that source information is encoded as a separate context and not as an integrated feature. Ecker, Zimmer, and Groh-Bordin (2007) showed that type of context matters. For instance, the authors argued that color information of objects, which has sometimes been understood as source information, is an intrinsically bound feature whereas background information is an extrinsic attribute. Put another way, item and color can be unitized whereas item and background are processed as two separate entities. In line with the unitization hypothesis, Ecker and colleagues showed that a color change from study to test significantly reduced the mid-frontal old/new effect compared with objects repeated in the same color. In contrast, a change in background did not have the same effect. Complementary behavioral evidence suggests that in addition to the type of source the way of encoding the source can influence memory processes (Diana et al., 2008). ROC estimates revealed that familiarity estimates for source memory are higher when color was encoded as a feature of the critical object, i.e. unitized (e.g., a green elephant), compared to when it was encoded as the feature of a context object (e.g., an elephant next to a green dollar bill). Moreover, source memory in a speeded response task (a condition which is assumed to eliminate recollection-based retrieval) was only above chance performance when source information was an intrinsic feature but not when it was encoded extrinsically (see Diana, Boom, Yonelinas, & Ranganath, 2011, for related ERP findings, and Staresina & Davachi, 2008, for related fMRI findings).

In sum, the above presented evidence strongly supports the possibility that remembering source information, a classic case of recollection, can be based on familiarity under conditions which promote unitization.

Semantic Associations and Pre-Existing Conceptual Units Stronger reliance on familiarity for pre-existing unitized word pairs such as compound pairs in contrast to semantically unrelated word pairs is one of the most extensively studied phenomena within this research area.

In an ERP study, Rhodes and Donaldson (2007) compared word pairs that shared only an associative relationship (e.g., *traffic-jam*), an associative and semantic relationship (e.g., *lemon-orange*), or only a semantic relationship (e.g., *cereal-bread*). Two words are associatively related if one word calls to mind the other word due to frequent common occurrence in language use. A semantic relationship exists if two words have overlapping features as for example 'four legs' as a feature of many animals. In other words, semantically related words belong to the same category. While the three types of pairs equally elicited a left parietal old/new effect, a mid-frontal old/new effect was evident only for the associatively related word pairs. This finding was expected because the pre-experimental ratings had revealed that association word pairs are perceived as more unitized than the other pair types. Moreover, the association words pairs could actually be regarded as compound words which as a whole denote one meaning. In a related study, Giovanello, Keane, and Verfaellie (2006) let amnesic patients with damage to the hippocampus perform an associative memory task with compound words (e.g., *pin-wheel*) and unrelated word pairs. Being forced to rely primarily on

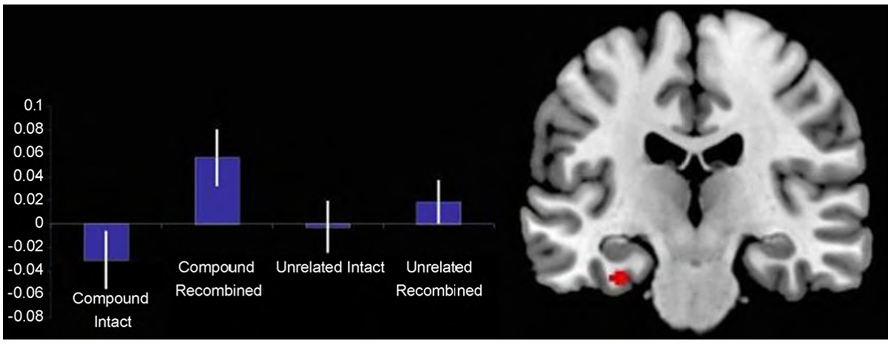


Figure 2.1.: Larger activation differences in the PrC for pre-existing unitized word pairs in contrast to unrelated word pairs during an associative recognition memory test in the study by Ford et al. (2010). This figure is reproduced from Ford et al. (2010, p. 3022) with permission from Elsevier.

familiarity, these patients showed significantly better associative memory performance for compounds than for unrelated word pairs. In an additional remember/know study with healthy participants, Giovanello and colleagues showed that the familiarity estimate for correctly recognized compounds was significantly higher than for unrelated pairs whereas the recollection measure did not differ. An fMRI experiment employing the same paradigm (Ford et al., 2010) also suggests a shift in the relative contribution of familiarity and recollection in healthy participants. This study showed an enhancement of perirhinal involvement for pre-existing unitized compared to unrelated word pairs (see Fig. 2.1).

The studies described so far in this section claimed to target familiarity-based associative memory. This is certainly the case in the sense that the task is an associative task (Rhodes & Donaldson, 2007) as participants have to distinguish between studied pairs (*pin-wheel*, *needle-point*) and recombined pairs (*pin-point*). However, the stimuli which were used in these experiments are seemingly all compound combinations which are associated with a single meaning. Thus, when *pin-wheel* is presented during study, there is no need to establish a new link between the representations of *pin* and *wheel* and thus, the task resembles very closely a simple item recognition task.

The study by Greve et al. (2007), which was already mentioned in section 1.4, used pairs which were not associated with a single meaning, but were semantically related. They found an enhanced mid-frontal old/new effect for these pairs which were preceded by a coherent category label in contrast to unrelated pairs which were preceded by an incoherent category label. At the same time, they found no difference for the late parietal old/new effect. Along these ERP findings, Greve and colleagues obtained behavioral estimates supporting the notion that familiarity, but not recollection, was enhanced for semantically related pairs. Applying the same paradigm with fMRI, Greve, Evans, Graham, and Wilding (2011) showed that processing of these types of word pairs at test is associated with different activation clusters within the MTL during study: related word pairs induced more perirhinal activation than unrelated word pairs. Kriukova (2012) further explored the influence of different kinds of pre-existing relationships on associative recognition memory. She compared categorically (semantically) related word pairs (e.g., *singer-actor*) with thematically (associatively) related word pairs (e.g., *singer-stage*) and found that both types elicited a mid-frontal old/new effect. However, the late parietal old/new effect was reduced for the thematically related pairs. Interestingly, in an additional behavioral forced-choice R/K recognition test, she could also show that correct recognition is more likely based on familiarity for thematically related pairs than for categorically related pairs.

Kriukova (2012) argued that thematically related pairs can more readily form a holistic scene (due to frequent co-occurrence) which is probably imagined and encoded as such by the participants during study. Although her data suggest that a categorical relationship seems to be sufficient in order to induce familiarity-based associative recognition, they also imply that the availability of a holistic representation emphasizes familiarity- over recollection-based recognition. In contrast, categorically related pairs are assigned to overlapping representations because they share many features. Kriukova's explanation for her and Greve and co-workers' (Greve et al., 2007, 2011) findings fit in a sense with the idea promoted by the DD-view (Mayes et al., 2007; Montaldi & Mayes, 2010). Both agree on the view that due to shared features related pairs have overlapping representations and can thus be recognized based on familiarity (although the findings for semantically related pairs by Rhodes and Donaldson (2007) described above are incompatible with this notion). However, it seems that belonging to the same domain does not necessarily imply shared features. This is probably the case for two unrelated words. While they both belong to the domain of 'words', feature overlap might be minimal because words are presumably processed for the most part conceptually. The shared features explanation for familiarity is implemented in the CLS approach to recognition memory. The neocortical system is thought to be able to remember associative information with overlapping features after multiple repetitions which is the case for semantically related word pairs (e.g., Norman & O'Reilly, 2003).

The key point to take from this section is that familiarity seems to be able to support associative recognition memory when it can take advantage of a quick reactivation of a well-established connection within semantic memory, be it categorical or thematic. Up to this point, the reviewed literature on the effects of unitization on associative recognition memory provides strong evidence that associative recognition memory can be based on familiarity when the association can be fit into a pre-existing frame (as in the case of faces), is encoded as a single item (as in the case of intrinsic feature binding and pre-existing compounds), or has already been established in semantic memory (categorical and thematic word pairs). This is in line with findings that suggest a strong relationship between familiarity and the semantic system (see section 1.4).

However, as already pointed out in the beginning of this chapter, associative recognition memory paradigms are commonly assumed to tap into a core competence of episodic memory, namely establishing new connections between previously discrete items during a single learning event. Thus, it remains an interesting question whether a shift from recollection to familiarity and from hippocampal to perirhinal involvement can also be found when an association is built during the event of study. In the following paragraphs, I turn to familiarity-based memory for novel associations.

Unitization as Encoding Strategy The formation of novel units as an encoding strategy and the mechanisms by which these novel units are retrieved constitute a special case as these processes are not confounded with any pre-existing associations. Instead, the link between the constituents is formed during one specific episode. It was suggested that one learning occasion is sufficient for unitization leading to subsequent familiarity-based remembering subserved by the PrC (e.g., Henke, 2010). Two different approaches have been applied so far. One approach is the interactive imagery study instruction. In this task, subjects have to form a mental image in which the parts of a pair interact with each other. This condition is contrasted with an item imagery task in which two separate images for each of the parts have to be imagined. The rationale of this manipulation is that an interactive image can be remembered as one thing whereas two item images have to be remembered through an additional link. The other approach is the formation of a novel concept during study. Participants learn pairs of previously unrelated words together with a definition which combines the two words to a novel concept (definition encoding: CLOUD-LAWN = A yard used for sky-gazing). A suitable and often used control condition with a comparable depth of semantic processing is the sentence encoding condition in which two words have to be inserted as distinct lexical items into a sentence frame (CLOUD-LAWN: He watched the ___ float by as he sat on the ___).

Using the interactive imagery approach, Rhodes and Donaldson (2008b) compared the ERP old/new effects during the retrieval of association word pairs and semantic word pairs (see Rhodes & Donaldson, 2007, above). A mid-frontal old/new effect was elicited for association word pairs equally after item and interactive imagery encoding. However, for semantic word pairs the mid-frontal old/new effect was enhanced after interactive imagery. Thus, word pairs which are not pre-experimentally unitized can also be encoded in a holistic manner and retrieved based on familiarity. In addition to this finding, this study reveals an interesting point about the associative pairs: it seems hard to break up the pre-existing unit as item imagery could not reduce the mid-frontal effect for these word pairs. This supports the notion that these word pairs are single items rather than true associations.

Studies using the definition encoding paradigm generally support the aforementioned implications from the interactive imagery study, but render the whole picture slightly more complicated. A neuropsychological study by Quamme et al. (2007) showed that the hippocampus is not inevitable for recognition of arbitrary pairings when unitization is used as an encoding strategy. This study found that amnesic patients with damage limited to the hippocampus, who exhibit severe recollection deficits, are much more likely to remember unrelated word pairs when the two words are combined to form a novel conceptual unit compared to when the two words are studied as distinct lexical items within the context of a sentence. In contrast, patients with damage to the hippocampus plus the surrounding MTLC performed equally poorly in both conditions. This suggests an increased contribution of MTLC mediated familiarity-based remembering for novel conceptual units. Using the same paradigm, Haskins, Yonelinas, Quamme, and Ranganath (2008) showed by means of fMRI that it is indeed the PrC being more engaged when previously unrelated word pairs are encoded as novel conceptual units. Moreover, activity variations in this region during encoding were associated with levels of subsequent familiarity as indexed by confidence judgments. This suggests an important role of the PrC for familiarity-based associative memory, which is comparable to familiarity for single items.

As described in the preceding paragraphs, the evidence in favor of familiarity-based recognition of novel conceptual units is quite strong. However, processes being engaged during retrieval might still not be the same as those during single item recognition as suggested by two recent ERP studies. Using the definition vs. sentence encoding paradigm, my colleagues and I (Bader, Mecklinger, Hoppstädter, & Meyer, 2010) found a significant difference in the contribution of early and late retrieval processes likely reflecting differential involvement of familiarity and recollection. The early old/new effect (350 – 500 ms) was greater than the late old/new effect (500 – 700 ms) in the definition encoding group, whereas the reversed pattern was found in the sentence encoding group. Notably, however, the early old/new effect, although being in the expected time window for a familiarity-related neural correlate, did not exhibit the typical mid-frontal distribution and was maximal over centro-parietal electrode sites. In order to test if this effect is indeed specific to novel conceptual units, Wiegand (2009) compared familiarity for novel conceptual units and single items directly in one experiment. After having studied word pairs in the definition encoding condition, participants were presented with either exactly the same versions of the studied pairs or pairs in reversed order. The rationale of this manipulation was that reversing the word pair disrupts the newly created unit as the exact configuration is a key feature of units (Haskins et al., 2008; Horowitz & Prytulak, 1969). Hence the effects of unitization were assumed to be present for same pairs only, while pure item recognition mechanisms should be diagnostic for reversed pairs. As expected, same and reversed pairs elicited two different topographical distributions. While same pairs were again associated with the early parietal old/new effect, reversed pairs elicited a mid-frontally distributed old/new effect in the same time window (see Fig. 2.2). Thus, familiarity for novel conceptual units and familiarity for single items exhibit different underlying neural correlates. Likely associated psychological processes are discussed in Chapter 3.

The core lesson from the current chapter is that familiarity-based associative recognition is possible. Moreover, this area of research has reconciled dual-process models of recognition memory with unexpected findings of perirhinal contribution to associative memory (e.g., Staresina & Davachi, 2006) by providing unitization as an explanation. However, although unitization has proven to be a sufficient condition for boost-

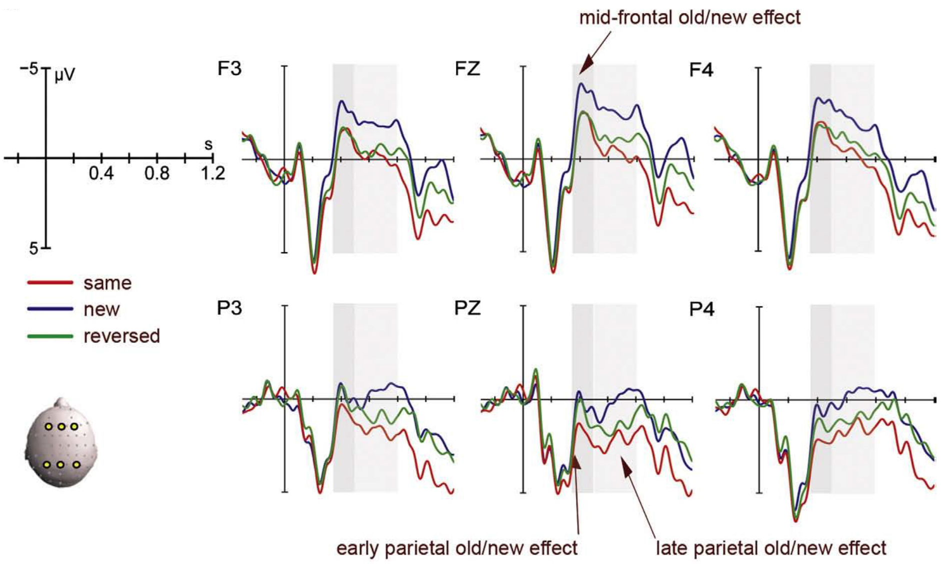


Figure 2.2.: ERP waveforms for correctly recognized old, reversed, and new responses at test when word pairs were encoded as novel conceptual units in the study by Wiegand (2009). Data are shown for frontal (F3, Fz, F4) and parietal (P3, Pz, P4) electrodes as indicated on the depicted electrode layout. This figure is reproduced from Wiegand et al. (2010, p. 110) with permission from Elsevier.

ing familiarity for associations, the findings for the semantically related word pairs suggest that it is not a necessary condition as it was proposed by Yonelinas (2002). High feature overlap might also be one factor as predicted by the DD view (Mayes et al., 2007). However, domain-membership per se is not the critical factor. Moreover, whether the retrieval processes for novel units are the same as for pre-existing units and single items is an unanswered question.

Detrimental Effects of Unitization on Recollection Before closing this chapter, this paragraph emphasizes that although research on the effects of unitization on associative recognition memory has primarily focused on familiarity, an effect on recollection has also been observed not in all but in a couple of studies. First and foremost, unitization influenced recollection in a negative way. For instance, in the study with morphed faces by Jäger et al. (2006), only inter-item associations but not intra-item associations elicited a left parietal old/new effect. The authors argued that the hippocampal system breaks down if the constituents of an association are too similar. This explanation might apply for this specific case but is not appropriate for unitized associations in general as they mostly do not consist of similar parts. The left parietal old/new ef-

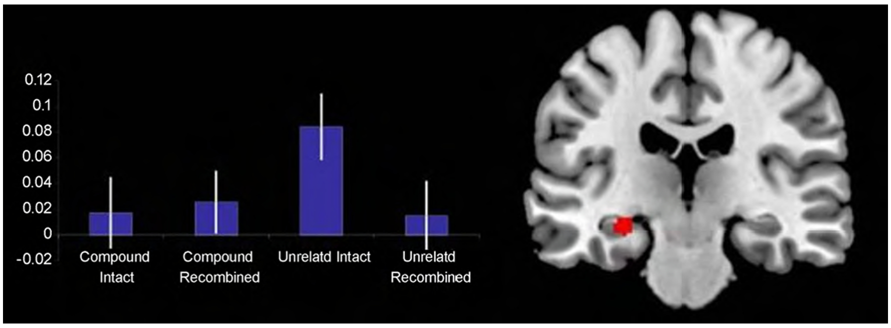


Figure 2.3.: Reduction of hippocampal activation for pre-existing unitized word pairs in contrast to unrelated word pairs during an associative recognition memory test in the study by Ford et al. (2010). This figure is reproduced from Ford et al. (2010, p. 3023) with permission from Elsevier.

fect also disappeared for novel conceptual units and thematic word pairs (Bader et al., 2010; Kriukova, 2012). Although the thematically related word pairs from Kriukova (2012) are associated in terms of their frequent co-occurrence, they do not share a lot of features. The word pairs used in our study (Bader et al., 2010) were even completely unrelated. Ford et al.'s (2010) fMRI experiment suggests that it is not just the absence of the left parietal old/new effect, but that even the core structure of the recollection network, namely the hippocampus, does not discriminate between studied and non-studied unitized pairs (see Fig. 2.3). Evidence that the absence of recollection is presumably not a failure of the hippocampal system (Jäger et al., 2006) which is caused by stimulus properties comes from studies where unitization did not have a detrimental effect on recollection (Giovanello et al., 2006; Rhodes & Donaldson, 2007; Wiegand, 2009). While these studies used stimuli which were very similar to the ones used in the aforementioned studies, it is possible that recognition test conditions especially promoted recollection. In the Wiegand (2009) study, word pairs were presented twice during study, a condition which is known to increase recollection (Jacoby, Jones, & Dolan, 1998; Opitz, 2010a). While Rhodes and Donaldson (2007) employed very short study-test cycles, Giovanello et al. (2006) collected R/K judgments. Both conditions might affect recollection positively, the former by shortening the retention interval (Yonelinas, 2002) and the latter by explicitly pointing to the possibility of remembering. Thus, it is possible that recollection is recruited to a lesser extent when familiarity already provides a very reliable signal in order to make recognition judgments and its contribution is only enhanced when it is triggered by the study or test conditions.

CHAPTER 3

Multiple Familiarity Signals?

As described in Chapter 2, the results from two ERP studies on recognition memory for novel conceptual units suggest that familiarity signals can be determined in multiple ways (Bader et al., 2010; Wiegand, 2009). Whereas pre-existing items were associated with a standard mid-frontal old/new effect, novel conceptual units elicited an early parietal old/new effect in the same time window. In this chapter, I shed light on the possible associated psychological processes.

3.1 Absolute and Relative Familiarity

As Mandler (1980) already elaborated on, each item has a raw familiarity or integration value at the time of encounter. This is the baseline or absolute familiarity of a specific item. For example, frequently encountered items exhibit a higher baseline familiarity (e.g., high frequency word *house*) than rarely encountered items (e.g., low frequency word *epee*). However, Mandler also claimed that a familiarity-driven recognition judgment is usually not based on this raw baseline familiarity value, but takes into account that the encounter during a specific episode leads to an increment in familiarity relative to baseline. This is a conceivable conclusion. Take the example of the word *house* which you might be tested on during a recognition memory experiment. Assessment of the baseline familiarity value would be quite meaningless because baseline familiarity would be quite high anyway due to the frequent occurrence of the word. An additional occurrence during the study phase of the experiment has only little impact.

3.1.1 Relative Familiarity

In support of the relative familiarity hypothesis, Stenberg, Hellman, Johansson, and Rosén (2009) established an association between the increment of familiarity and the mid-frontal old/new effect. In this study, the factors frequency and fame of names were manipulated orthogonally in order to compare ERP old/new effects for common vs. rare names as well as famous vs. non-famous names. The authors argued that baseline familiarity is basically determined by the frequency (and not fame) of the names implying that for less frequent names the increment should be greater. Although it could be argued that famous names should also occur more frequently than non-famous names, the general expectancy for a rare name belonging to a famous person such as Barack Obama is – especially in the context of a recognition memory experiment – still lower than that for a frequent name of a famous person such as George Bush. In line with this rationale, recognition judgments for famous and non-famous names were associated with a comparable early mid-frontal old/new effect whereas rare names elicited a larger mid-frontal effect than frequent names. Thus, these findings implicate that the mid-frontal old/new effect constitutes an index of the increment in familiarity.

3.1.2 Absolute Familiarity

Although the increment in familiarity might be the best indicator of prior occurrence during a recognition memory experiment, it is doubtful that it is similarly useful when encountering someone on the bus (see Yovel & Paller, 2004, for a similar argument). In order to know whether you are supposed to say "Hello" to this person, a global absolute familiarity signal is most informative as it is completely irrelevant whether you got to know this person just this morning or last summer. The same considerations hold for recognition of novel units. In order to decide whether you have learned the novel concept *cloud-lawn* it is sufficient and highly effective to check whether you know the meaning of *cloud-lawn* or not. This turns recognition memory into a semantic rather than an episodic task. This implication is consistent with the properties of the early parietal ERP old/new effect found for novel conceptual units (Bader et al., 2010; Wiegand, 2009). Interestingly, in topography and timing the early parietal old/new effect closely resembles the N400 effect, which commonly exhibits a similar mid/right centro-parietal distribution and occurs in the same time window (see Box 1.2). It might be that studied novel concepts elicit a reduced N400 compared to new words at test because they have been semantically integrated during the study phase by means of the definition provided. Crucially, the facilitated semantic processing reflected by the reduced N400 is diagnostic in this test as new pairs have not been semantically integrated before.

A similar reasoning can be applied to the aforementioned example of encountering someone on the bus. In an attempt to investigate this phenomenon in an experimental setting, participants have to study novel faces along with a name or an occupation. Test trials in which participants recognize the face but not the accompanying information are taken as the operational definition of pure familiarity (without recollection). In such a study, Yovel and Paller (2004) did not find evidence for an early old/new effect related to familiarity but only a later effect which was indistinguishable from the recollection related effect. However, MacKenzie and Donaldson (2007) found an early old/new effect for face familiarity which exhibited a parietal maximum comparable to the results for novel units (Bader et al., 2010; Wiegand, 2009). Importantly, this effect was topographically dissociated from the later recollection effect which had a more anterior maximum. MacKenzie and Donaldson explained the two diverging findings by the higher electrode density they applied which is probably better suitable to identify subtle topographic differences. Moreover, the face pictures they used were freed from any contextual details such as hair, clothes, and background emphasizing on familiarity processing. MacKenzie and Donaldson interpreted the early parietal old/new effect as an index of absolute familiarity. They also noted that task demands might be a critical determinant for the type of familiarity assessed during a recognition test. For example, Nessler, Mecklinger, and Penney (2005) found a more frontally distributed effect for the comparison of famous and non-famous faces in a continuous recognition paradigm which has different strategic requirements than a standard study-test-recognition experiment. Taken together, the findings described so far permit the conclusion that reliance on absolute familiarity might be indexed by a parietal distribution of the early old/new effect although the conditions under which assessment of absolute familiarity is stressed over the increment of familiarity still have to be determined.

Coane, Balota, Dolan, and Jacoby (2011) were the first to isolate incremental and absolute familiarity behaviorally in a two-list-exclusion paradigm. Participants studied high and low frequency words of an auditory and a visual list but only words from the auditory list had to be endorsed as 'old' whereas those from the visual list and new items had to be endorsed as 'new'. Hence, an 'old' response to a studied visual word is an exclusion error. Absolute familiarity should contribute to the decision for studied as well as unstudied items. In contrast, relative familiarity can only be diagnostic for studied items because an increment of familiarity is only possible for already presented items. In order to exclude the contribution of recollection, a response-deadline was applied. In line with their expectations, they found higher hit rates for low frequency than high frequency words along with higher exclusion error rates for low frequency words. Coane and colleagues attributed this to higher relative familiarity for low than for high frequency words. Moreover, in at least one of two experiments they also found higher FA rates for high frequency new words compared to low frequency new words. Thus, also absolute familiarity is assessed during recognition memory decisions.

3.2 Discrepancy-Attribution-Hypothesis

The concept of absolute familiarity is tied to the idea of conscious access to one's semantic memory. However, an alternative although not contradictory interpretation of the early parietal old/new effect is also possible. In several articles, Whittlesea and Williams (e.g., Whittlesea & Williams, 1998, 2000, 2001b, 2001a) argued that familiarity is per definition a diverse concept and that the evaluation of memory strength is not the only way of producing familiarity signals. They claimed that especially this strong feeling of familiarity, when you meet someone for who you neither remember the name nor any other episodic information but who you are completely sure to know, is based on an attribution process. Whittlesea and Williams further developed the idea of a fluency heuristic for recognition memory (Jacoby & Dallas, 1981) which is grounded in the phenomenon that stimulus repetition leads to enhanced fluency during processing. Thus, the experience of fluent processing can be attributed to a prior encounter. Jacoby and Dallas (1981) already noted that it is not the absolute fluency which determines if a familiarity attribution takes place but rather the increase in fluency due to the study phase encounter (this might relate to the notion of increment in familiarity). They showed that naming times of low-frequency words in contrast to high-frequency words are disproportionately enhanced when presented for the second time. Moreover, in a recognition test, they found greater hit rates for low-frequency words than for high-frequency words.

Thus, greater discrepancy of actual fluency and baseline fluency correlates with a greater probability of being recognized. However, Whittlesea and Williams (1998) argued that the attribution of fluency does not only depend on stimulus characteristics but also on context. Whereas you do not expect to meet your butcher on the bus, you strongly expect to encounter him in the butcher's shop. Moreover, attribution of fluent processing to familiarity only takes place in the former but not the latter case. In a series of experiments, Whittlesea and Williams showed that fluent processing is attributed to a source in the past whenever it is unexpected. For example, regular non-words (e.g., hension) are presumably processed more fluently than irregular non-words (e.g., stofwus). The fluent processing, however, is not expected as this is usually associated only with meaningful words. In line with this, regular non-words attract more 'old' responses than words in recognition tests (Whittlesea & Williams, 1998). Note that not only perceptual fluency but also conceptual fluency augments the number of 'old' responses. Evidence comes from studies which increased fluency by means of a preceding semantic prime (Rajaram & Geraci, 2000) or a preceding predictive sentence stem (e.g., Whittlesea & Williams, 2000). Importantly, the increase in 'old' responses can basically be traced back to more 'know' and not 'remember' responses to those items (Rajaram & Geraci, 2000; Whittlesea & Williams, 2000).

Arguments against the use of fluency as a recognition heuristic such as the finding of completely impaired recognition memory despite intact perceptual or conceptual priming in amnesic patients (Conroy, Hopkins, & Squire, 2005; Levy, Stark, & Squire, 2004) have to face the notion that the influence of fluency on recognition memory comes with prerequisites. Apart from the unexpectedness (e.g., Whittlesea & Williams, 1998), coherence was identified as one factor. To this effect, perceptual fluency is not effective when modality changes from study to test. For example, if visual fluency is perceived as enhanced during test, participants take into account that it is unlikely to arise from presentation during an auditory study phase (Miller, Lloyd, & Westerman, 2008). Moreover, salience of fluency (Whittlesea & Williams, 2000) also seems to be important. Accordingly, Keane, Orlando, and Verfaellie (2006) showed that an increase in the salience of fluency as a hint for being studied enhanced the performance of amnesic patients in a recognition memory test.

There are also hints from ERP research that fluency plays a role during recognition memory tasks. Wolk et al. (2004) showed that test items following predictive sentence stems were associated with a reduced N400 in contrast to test items following non-predictive sentence stems. Although this is complemented by their finding that test items after predictive sentence stems were more likely endorsed as ‘old’ than those after non-predictive stems, they failed to show that the N400 is modulated by the type of response. Thus, the N400 amplitude did not differ for ‘old’ and ‘new’ responses. Therefore it is unclear to what extent fluency reflected by a reduced N400 really directly triggered ‘old’ responses. Woollams, Taylor, Karayanidis, and Henson (2008) used masked repetition priming to increase fluency of test words. In the N400 time window, they statistically dissociated two different effects. On the one hand, they found an old/new effect maximal over frontal electrode sites and on the other hand, they found an effect of priming with a parietal maximum. Due to an overlap of the two effects, it is impossible to determine if the parietal component is also sensitive to response type. However, on the behavioral level, masked priming increased the likelihood of ‘old’ responses. In sum, ERP evidence in favor of fluency processing which is deterministic for the recognition decision is rather weak, but there is first evidence for the relevance of fluency during recognition decisions.

Coming back to the initial question of familiarity for novel units, it is important to note that the discrepancy-attribution-hypothesis explicitly states that “the phenomenological state of familiarity is not associated only with context-free, item-based processing but instead with any processing that is experienced as discrepant” (Whittlesea & Williams, 2000, p. 561). Thus, it is a concept of familiarity which is especially applicable to associative recognition memory. Specifically, unitization seems to be a perfect candidate in order to induce fluent processing as Whittlesea and Williams emphasize that processing fluency means the quality of processing. They refer, for instance, to “the degree to which the component features of a stimulus configure into an integral whole when processed” (Whittlesea & Williams, 1998, p. 163). Moreover, as the expected fluency for pre-experimentally unrelated word pairs is practically zero, the discrepancy between expected and actual fluency for novel units is disproportionately high. In addition, conceptual fluency at test is coherent with the semantic study phase task and it is a salient diagnostic feature of the studied pairs in contrast to the new pairs. In strong support of the conceptual fluency hypothesis of familiarity for novel units, reaction times for correctly recognized same pairs are faster than for correctly recognized reversed pairs, for which a disruption of the concept is assumed

(Wiegand, 2009). Moreover, since in the Wiegand (2009) study participants rated the plausibility of the definition during the study phase, test pairs could be sorted into well integrated (i.e. plausible definition at study) and poorly integrated (i.e. implausible definition at study) pairs. Post-hoc analyses revealed that well integrated pairs were recognized faster than poorly integrated pairs when presented in same, but not in reversed order. As accelerated processing is one of the main behavioral manifestations of fluency, this is further evidence that conceptual fluency is enhanced because of successful unitization. Further substantiating this notion, the early parietal old/new effect for same pairs was present only for well integrated pairs but not for poorly integrated pairs. In contrast, the mid-frontal effect for reversed pairs was observed irrespective of integration/unitization quality (Wiegand et al., 2010).

In sum, it is important to note that it is impossible and also not necessary to adjudicate between the absolute familiarity account and the discrepancy-attribution-hypothesis. Whereas the former is related to stimulus characteristics, the latter is based on processing characteristics. Moreover, interestingly Coane et al. (2011) establish a link between relative familiarity and discrepancy attribution as the discrepancy is greater when baseline familiarity is lower. Thus, the exact interrelations between absolute familiarity, relative familiarity, discrepancy-attribution and possible other sources of feelings of familiarity still have to be determined. It is only clear that it is crucial to distinguish between different kinds of familiarity and to acknowledge that probably different neural networks are involved.

CHAPTER 4

Research Questions

4.1 Recognition Memory for Associations with Different Degrees of Unitization

Yonelinas et al. (2010) emphasized that unitization should be regarded as a continuum rather than a dichotomy (see also Section 2.1). The different ways to induce unitization introduced in Section 2.3 result in associations which can be placed on different positions on that continuum. Figure 4.1 depicts a sketch of the continuum for those types of unitization which are most relevant to the current thesis. Degree of unitization in this classification was inferred from the perceived rigidity. i.e. how difficult it is to break up the unit.[1] Single items such as words are supposed to constitute the highest degree of unitization. As they have a pre-experimental familiarity, only the increment in familiarity (relative familiarity) can be diagnostic for occurrence during a specific study episode. The mid-frontal old/new effect is postulated to be the corresponding ERP correlate (Stenberg et al., 2009) and the PrC was found to be deactivated for familiar in contrast to new items (e.g., Henson et al., 2003; Montaldi et al., 2006). A highly similar picture can be drawn for pre-existing units. Although being de-constructable, they appear so frequently as a unit that they have as a whole a pre-experimental familiarity implicating relative familiarity during a recognition test. In line with this, a mid-frontal old/new effect (Rhodes & Donaldson, 2007) and modulation in the PrC (Ford et al., 2010) were reported for these pairs. Pre-existing associations were shown to elicit a mid-frontal effect,

[1]Note that as it is an unresolved question to date how to measure the degree of unitization, this is a subjective classification serving as a working hypothesis.

degree of unitization	example	process	ERP effect	brain region
item	*house*	relative familiarity	early mid-frontal	PrC
pre-existing unit	*traffic-jam*	relative familiarity	early mid-frontal	PrC
pre-existing association	*singer-stage/ singer-actor*	relative familiarity	early mid-frontal	?
novel unit	*vegetable-bible* *= a book consulted by hobby gardeners*	absolute familiarity	early parietal	?
arbitrary association	*frog-pencil*	only recollection	late left-parietal	hippocampus

Figure 4.1.: Overview of different degrees of unitization. Degree of unitization is increasing from bottom to top. For each degree, examples, the hypothesized primary retrieval process, the putative ERP correlate (old/new effect) and the underlying brain region activated during retrieval are presented. Note that in the cases where familiarity-based retrieval is indicated, additional recollection is not necessarily excluded. PrC = perirhinal cortex.

too (Kriukova, 2012; Greve et al., 2007). Due to their pre-experimental joint occurrence they have a pre-experimental familiarity and a relative familiarity mechanism during recognition is conceivable. The brain regions involved during retrieval of those pairs have not yet been investigated. However, one encoding study is suggestive of an involvement of the PrC (Greve et al., 2011). For novel units it was postulated that due to pre-experimental unrelatedness an absolute familiarity signal can be diagnostic and the corresponding ERP effect would be the early parietal old/new effect (Bader et al., 2010). While the PrC was shown to be involved during encoding of novel conceptual units (Haskins et al., 2008), to the best of my knowledge there is no study which has examined the neural network activated during retrieval yet. The lowest degree of unitization in Figure 4.1 is represented by arbitrary associations as they are not tied to an exact configuration. For the retrieval of this kind of associations, recollection is assumed to be essential, a claim which is supported by findings of the left parietal old/new effect (Donaldson & Rugg, 1998; Jäger et al., 2006; Bader et al., 2010) and activation of the hippocampus during retrieval (Giovanello et al., 2004).

4.2 Dissociating Retrieval Processes for Novel Concepts from those for Pre-existing Units and Items

The overview in Figure 4.1 reveals two major gaps in our knowledge about the retrieval processes involved in associative recognition memory: the neural network involved in the retrieval of pre-existing associations and the the neural network involved in the retrieval of novel units. The current thesis primarily focuses on the retrieval processes for the latter and their dissociation from those for non-unitized associations, pre-existing units and single items. Novel units are highly interesting in at least two ways. First, the creation of units during a study event accomplishes the unique ability of episodic memory to readily form a link between two or more items, an ability which is usually associated with the hippocampus (e.g., Norman & O'Reilly, 2003). This is not the case for pre-existing associations. Second, the ERP effects reported for this kind of pairs are suggestive of a unique way of processing presumably associated with absolute familiarity. Thus, in the main part of this thesis, novel units are compared to novel associations which are not unitized in a between-group design (Experiment 2) and to pre-existing units in a within-group design (Experiment 3).

Specifically, Experiment 2 aimed to examine the neural network underlying the retrieval of novel conceptual units by means of fMRI. To this end, the paradigm used by Wiegand (2009) was employed for one group and contrasted with a sentence encoding group. While for the sentence encoding group a predominant role of the recollection network was expected based on related ERP (Bader et al., 2010) and fMRI findings (Giovanello et al., 2004), precise predictions for the definition encoding group were difficult to derive. Findings from an encoding study (Haskins et al., 2008) suggest the involvement of the perirhinal cortex. Moreover, as this region is also important for conceptual processing in general (e.g., K. I. Taylor, Moss, Stamatakis, & Tyler, 2006), it is probably also involved during retrieval. However, the previous ERP studies suggest that the brain regions activated during retrieval for novel conceptual units are at least partly different from those activated during retrieval of pre-existing units. The second aim of Experiment 2 was to contrast the neural networks involved in familiarity for novel units (absolute familiarity) and familiarity for single items (relative familiarity). Therefore, in addition to same pairs, reversed versions of the studied pairs were presented at test for which the conceptual unit is assumed to be disrupted.

Wiegand (2009) found faster reaction times for same pairs compared to reversed pairs. This was interpreted as enhanced conceptual fluency which is specific to the unitization encoding. Alternatively, the fact that the pairs were repeated as an exact copy for same pairs but with a perceptual change for reversed pairs could have led to the speed-up in response times. Hence, the aim of Experiment 1 was to rule out this possibility before this manipulation was applied in Experiment 2. Thus, in Experiment 1 the same test conditions as in the study by Wiegand (2009) were applied. However, during study, participants had to follow a sentence encoding instruction. The results were compared to those of the definition group from the Wiegand study. The speed advantage for same in relation to reversed pairs was expected to be reduced for the sentence group.

The goal of Experiment 3 was to substantiate the existence of two topographically different early old/new effects by dissociating them within one experiment. Therefore, in order to manipulate the pre-experimental familiarity while holding the stimulus characteristics otherwise constant, pre-existing units (compound pairs) and novel conceptual units (definition encoding) were directly contrasted. While for the former a mid-frontal old/new effect was predicted, the latter were expected to elicit an early parietal old/new effect based on the findings by Rhodes and Donaldson (2007) or Bader et al. (2010) and Wiegand (2009), respectively.

4.3 Stretching the Unitization Continuum: Unitization in the Pictorial Domain

Experiment 4 was a behavioral study with the aim to stretch the continuum of unitization. Unitization of previously unrelated items during encoding was applied in the pictorial domain inducing unitization by creation of a scene. While following studies using interactive imagery, the design of Experiment 4 provides a better control of the actually studied representations. Moreover, effects of unitization of unrelated items on familiarity-based recognition memory have until now only been found for verbal material. Effects on familiarity were isolated by means of a repsonse-deadline procedure (e.g., Mecklinger et al., 2010, see Section 1.2.2). Thus, better memory performance under speeded response conditions was predicted for the picture pairs which were arranged as a scene compared to those which were not arranged as a scene.

CHAPTER 5

Experiment 1*

5.1 Introduction

As already described in Section 2.3 and Chapter 3, Wiegand (2009) dissociated two early ERP old/new effects for novel conceptual units and pre-existing items, respectively. This was accomplished by means of two different test cues to probe memory for word pairs studied together with a definition combining the pair to a novel compound. Same pairs were exact repetitions of the studied pairs which was intended to maintain the novel unit. In contrast, it was assumed that the unit is disrupted when word pairs were presented in reversed order as the configuration of a unit is considered to be rigid (Horowitz & Prytulak, 1969). However, although familiarity for the whole unit is not assumed to occur, the constituents should still be familiar at test. As the constituents are pre-existing single words, it can be assumed that they undergo an increment in familiarity and elicit a relative familiarity signal.

Support for the disruption of the unit was provided by Haskins et al. (2008) in a supplemental behavioral study. They compared recognition accuracy for word pairs encoded under definition encoding compared to word pairs encoded under sentence encoding conditions. In this latter condition, the sentence provides an external link for the separate single words. It is believed that associations built in this way are more flexible than the rigid units and recollection is needed to remember these kinds

*The results of Experiment 1 were partially published together with the findings reported in Wiegand (2009) in *Brain Research.* Starting from the next chapter, reference to the results obtained by Wiegand (2009) and those from Experiment 1 is made as Wiegand, Bader, and Mecklinger (2010).

of associations (see also Bader et al., 2010; Quamme et al., 2007). Given that recollection is the core process contributing to recall (e.g Baddeley et al., 2001), findings from recall implicate that recollection is flexible with respect to word order (Kahana, 2002). Thus, reversing the pair is not expected to impair performance for recollection-based retrieval as in the sentence encoding task. In support of this notion, Haskins et al. (2008) found better performance in the definition group than in the sentence group only for same pairs, but not reversed pairs. The authors took this as evidence that the creation and maintenance of a unit is important to enhance associative recognition memory (presumably by increased familiarity).

As outlined in Chapter 3, a tempting explanation of the parietal shift in the distribution of the early old/new effect for novel conceptual units is the enhanced conceptual fluency or facilitated semantic access for studied word pairs reflected in an N400-like component (Bader et al., 2010; Wiegand, 2009). This interpretation is supported by the finding that same pairs are recognized faster than reversed pairs, which can be interpreted as an indicator of enhanced fluency for novel units. It is possible, however, that a pure perceptual repetition effect caused the shorter response times for same pairs. Same pairs were the only test cues which were repeated without perceptual change from study to test. However, if unitization causes the speeded responses to same pairs, reaction times to same and reversed pairs should not differ if the pairs have not been unitized during study. As Haskins et al. (2008) have not reported reaction times, the aim of Experiment 1 was to test this hypothesis in a supplementary behavioral study to the Wiegand study. This was a neccessary prerequisite in order to substantiate the validity of the same vs. reversed manipulation as a dissociation between unit and item specific processes for subsequent studies.

To this end, a separate group of participants was tested in the sentence encoding paradigm. In the study phase, the same set of word pairs was used, but were presented together with a sentence frame (e.g., VEGETABLE BIBLE - This ___ was already mentioned in the ___.). The test phase was exactly the same as in the Wiegand study: participants had to discriminate between same, reversed, recombined, and new pairs. The same and reversed pairs had to be classified as ‘old’ and the other two pair types as ‘new’. As the data obtained in Experiment 1 were directly compared to the behavioral data obtained in the Wiegand (2009) study, I describe the current experiment as the sentence group whereas the Wiegand (2009) experiment is referred to as the definition group. I hypothesized the difference in reaction times between same and reversed pairs to be larger in the definition group than in sentence group. Analogously, the results by Haskins et al. (2008) suggest that same pairs are remembered better than reversed pairs in the definition group whereas this difference should be smaller in the sentence group.

5.2 Methods

Generally, methods were set up in order to match the definition group in Wiegand (2009). Methods are described for both groups as data of both groups entered the analyses.

5.2.1 Participants

Data of 18 participants (10 female) were analyzed in the definition group. Mean age in the definition group was 22.18 (range: 19–26). Nineteen participants took part in the sentence group. Data of one participant had to be excluded because of failure to follow the instructions. Mean age of the remaining 18 participants (10 female) was 23.39 (range: 20–30). All participants were native German speakers and right-handers as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971). They had normal or corrected-to-normal vision and were reimbursed 8 Euros/hour or received course credit for participation. The experiment was approved by the local ethics committee.

5.2.2 Material

The study phase stimuli consisted of 126 unrelated German word pairs (see Appendix A.1 and A.2 for a full list of stimuli). Unrelatedness was assured by a pre-experimental rating study in which participants ($n = 59$) had to judge the relatedness on a 4-point scale. Only pairs which were rated as unrelated were considered. Word length was 4–10 letters and mean lexical frequency was 10–500 per million (Baayen, Piepenbrock, & Gulikers, 1995). In the definition group, pairs were presented together with a definition combining the words to a novel concept. Definitions consisted of a noun phrase followed by a relative clause (e.g., VEGETABLE BIBLE – A book which is consulted by hobby gardeners.) In the sentence group, pairs were presented together with a sentence frame. The words were not repeated in the sentence frame but were replaced with blanks in which participants had to fill in the words (e.g., VEGETABLE BIBLE – This ___ was already mentioned in the ___). Each word pair was presented twice in the study phase. Study list composition was pseudo-randomized with the constraint of a 10–30 items lag between two identical study cues.

The test phase included 168 pairs. 42 same pairs were exact repetitions of the studied pairs, 42 reversed pairs were studied in the same combination but in reversed order, 42 recombined pairs consisted of new combinations of studied pairs, and 42 new pairs were not studied. Assignment of the 126 study pairs to the conditions old, reversed, and recombined was counterbalanced across participants. The 42 new pairs were equal for all participants. In a second rating study ($n = 43$) the unrelatedness of recombined and new pairs was approved. In the pseudo-randomized test lists, no more than three items of the same pair type were presented in a row.

5.2.3 Procedure

The experiment was programmed using E-Prime (Psychology Software Tools, Inc.). Only the definition group was prepared for electroencephalogram (EEG) recording and was tested in the EEG lab. The sentence group was tested under comparable conditions in front of a standard PC. All stimuli were displayed in Arial font white letters on black background. During the study phase, word pairs were presented in 24 pt upper-case letters. Definitions or sentences were presented simultaneously slightly below the pair in 20 pt font. The definition group had to rate how well the definition combined the words into a novel compound while the sentence group was instructed to rate the plausibility of the sentence with the two words inserted into the blanks. Subjects had to use a 4-point scale for the rating ranging from 1 ("very badly") to 4 ("very well"). A trial began with a 200 ms fixation cross, followed by a 200 ms blank screen and the presentation of the word pair and the definition/sentence for 5000 ms. After another blank screen of 50 ms, the response window, during which a question mark was presented, appeared for 1500 ms. The keys 'x', 'c', 'n', and 'm' on a standard German keyboard corresponded to the responses 1–4. Participants used their middle and index fingers of both hands. After every 42 trials, participants had the possibility for a self-paced break.

After a 5 min distractor task in the retention interval, participants were informed about the upcoming memory test. The test phase was exactly the same in both groups. Same and reversed pairs had to be classified as 'old' whereas recombined and new pairs had to be classified as 'new' by pressing the keys 'c' and 'n' with the index fingers of both hands. Key assignment was counterbalanced across subjects. After a 500 ms fixation cross and a 300 ms blank screen, the stimulus was presented for 750 ms followed by a 2000 ms blank screen. Responses were allowed from onset of the test pair until the end of the blank screen. Then, participants had to make a confidence judgment ('sure' and 'unsure') within maximally 3000 ms. After 42 trials there was a self-paced break.

5.2.4 Data analysis

Descriptive statistics are provided for all four pair types. However, as the purpose of this study was to compare performance for same and reversed pairs, inferential statistics are restricted to these two conditions. Repeated-measures analyses of variance (ANOVA) were used to analyze the data. The significance level was set to $\alpha = .05$.

5.3 Results

As can be seen in Figure 5.1, accuracy was generally on a high level. However, there were differences between same and reversed test pairs. This was substantiated by an ANOVA on percentage correct with the between-subjects factor Encoding Group (definition, sentence) and the within-subjects factor Pair Type (same, reversed). The analysis revealed a main effect of Pair Type ($F(1, 34) = 11.10, p < .01$), but neither a main effect of Encoding Group ($F < 1$) nor an interaction ($F < 1$). These findings indicate that there is a general forward advantage, which is comparable for the definition group ($same : mean\ (M) = .86, standard\ error\ (SE) = .02; reversed : M = .82, SE = .02$) and the sentence group ($same : M = .85, SE = .02; reversed : M = .82, SE = .02$).

An ANOVA on the reaction times with the between-subjects factor Encoding Group (definition, sentence) and the within-subjects factor Pair Type (same, reversed) yielded a significant main effect of Pair Type ($F(1, 34) = 24.11, p < .001$) and a significant interaction of Pair Type $\times$ Encoding Group ($F(1, 34) = 6.68, p < .05$). The main effect of Encoding Group was not significant ($F < 1$). Follow-up t-tests revealed that same

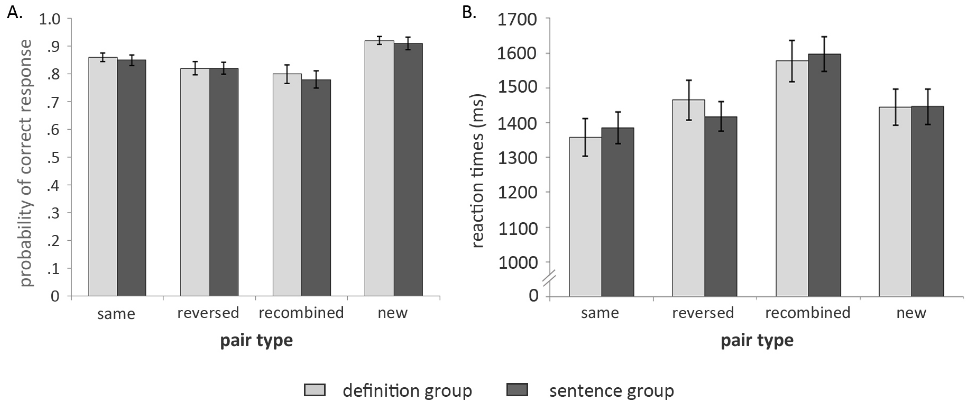


Figure 5.1.: Mean probabilities of correct responses (A.) and mean reaction times (B.) for same, reversed, recombined, and new pairs in the definition and sentence encoding group of Experiment 1. Error bars indicate 95% confidence intervals for the interaction term (Jarmasz & Hollands, 2009).

pairs ($M = 1358, SE = 53.50$) were recognized faster than reversed pairs ($M = 1465, SE = 52.33$) in the definition group ($t(17) = 5.40, p < .001$), but not in the sentence group ($t(17) < 1.74$). Thus, speeded reaction times for same pairs in contrast to reversed pairs could only be observed in the definition group and not in the sentence group.

5.4 Discussion

In Experiment 1, participants studied word pairs within sentence frames as separate lexical items. The results were directly compared to the behavioral data obtained by Wiegand (2009) in order to test whether the behavioral advantage for same in contrast to reversed test pairs observed for pairs encoded in the definition encoding condition can be attributed to the maintenance of the conceptual unit or to the perceptual repetition of the study cue. Analysis of the accuracy data revealed generally better performance for same compared to reversed pairs, which was not modulated by study group. In contrast, faster responses for same pairs in contrast to reversed pairs were selectively found in the definition group and virtually absent in the sentence group.

The main focus of this experiment was the comparison of the reaction times as the faster responses to same pairs were previously attributed to enhanced conceptual fluency. The significantly smaller difference in reaction times for same and reversed pairs in the sentence group supports this interpretation because conceptual fluency should prevail for novel concepts and be less relevant for word pairs encoded within sentence frames. The explanation that the speed advantage was caused by the repetition of the study cue at test can be ruled out by the current results.

In contrast to Haskins et al.'s (2008) data, better performance for same compared to reversed pairs was found in both encoding groups. As this merits further discussion, it might be valuable to consider other studies which investigated memory for forward and backward associations, i.e. same and reversed test cues. Comparing recognition and cued recall for forward and backward associations, an experimental series conducted by Yang et al. (2013) consistently showed that a forward advantage with respect to memory performance exists only for recognition but not recall and that this pattern is independent of the type of association (related vs. unrelated word pairs). Giovanello et al. (2009) could also demonstrate a forward advantage in a recognition task, no matter if the pairs were originally encoded within one or two sentences. Yang et al. (2013) propose that the recall vs. recognition dissociation might be explained by the different processes contributing to the two tasks. Whereas recall primarily depends on recollection, recognition can generally be subserved by recollection and familiarity. The authors further argue that there might be familiarity for the associative sequence which can only be beneficial if the pair is presented as a whole such as in a recognition task and not if only one of the constituents serves as the test cue. However, this explanation is not reconcilable with the general finding that the contribution of familiarity to recognition of (non-unitized) word pairs is negligible (e.g., Donaldson & Rugg, 1998). Another possible interpretation is that the direction of an association is a feature which is generally encoded (Kahana, 2002) and thus can serve as an additional cue during recognition increasing the performance. In cued recall, direction is not presented as a cue and thus cannot influence performance in favor of forward associations. The presentation of an additional test cue could generally have positive effects on both, recollection and familiarity.

Irrespective of the explanation, the current results add to the existing findings that associative recognition is better for forward than for backward associations. One possible reason why the Haskins et al.'s (2008) sentence encoding data diverges from the current data are the different types of list composition. Haskins and colleagues presented definition and sentence encoding trials intermixed during the study whereas the current experiment used a between-subjects design. In a blocked or between-subjects design, participants can adapt their retrieval strategies as maximally suitable for the respective task. However, in a mixed list participants probably concentrate on the most salient items. It is not unlikely that in the case of the Haskins et al. study, the novel conceptual units were most prominent leading to an emphasis on familiarity-based recognition. This in turn generally decreased the performance in the sentence condition – also for forward pairs.

An alternative explanation for the divergent results of the Haskins et al.'s (2008) study and the current experiment could be the different numbers of study repetitions. While in the Haskins et al. study each word pair was studied only once, there were two study presentations in the current study. This might have enhanced memory performance for the reversed pairs by boosting recollection. The finding of a left parietal old/new effect for the definition group (Wiegand, 2009) is consistent with this explanation.

In summary, the current findings support the notion that the speed advantage of same vs. reversed pairs in a definition encoding paradigm can be attributed to increased conceptual fluency and cannot be explained by the identical study cue repetition for same but not for reversed pairs. Thus, the formation of a novel unit induces unique processing characteristics which strongly rely on the exact configuration of the unit. Importantly, Experiment 1 adds further evidence that the manipulation used here can dissociate between novel conceptual units and pre-existing single items. This is important for the use of this design in Experiment 2.

CHAPTER 6

Experiment 2

As described in Chapter 2.3 recent advancements of dual-process models of recognition memory state that an association between two or more items can be familiar if the parts are unitized (Diana et al., 2007; Ranganath, 2010; Yonelinas, 2002; Yonelinas et al., 2010, 1999). As argued before, it can be distinguished between pre-existing units (i.e. stored in semantic memory) and newly created units. Various methodological approaches showed that in comparison to unrelated word pairs (e.g., *poker-curl*), familiarity-based memory is enhanced for pre-existing units such as compound word pairs (e.g., *motor-cycle*, Rhodes & Donaldson, 2007; Giovanello et al., 2006). Regarding the neural basis, findings from a recent fMRI study suggest a shift in the relative contribution of different MTL structures as they showed a reduction of hippocampal activation and an enhancement of perirhinal involvement for pre-existing unitized in contrast to unrelated word pairs (Ford et al., 2010). This has been taken as evidence that pre-existing unitized associations are remembered in a comparable way to single items.

However, is this also the case for previously unrelated items which are unitzed not until encoding? As described in Section 2.3, it was suggested that one learning occasion is sufficient for unitization to induce subsequent familiarity-based remembering subserved by the PrC (e.g., Henke, 2010). As evident from Figure 4.1, this has not yet been investigated. Quamme et al. (2007) showed that patients with damage limited to the hippocampus can perform above chance-level when two unrelated words are studied in a definition encoding condition compared to a sentence encoding condition. In contrast, patients with a damage comprising also the surrounding MTLC did not benefit from definition encoding. This suggests an increased contribution of MTLC mediated familiarity-based memory for unitized associations. Using the same paradigm in an fMRI study, Haskins et al. (2008) showed that the PrC is more engaged when previously unrelated word pairs are encoded as novel conceptual units. However, the brain structures involved in the retrieval of novel conceptual units cannot readily be inferred from these studies.

As outlined in Chapter 3, the results from two recent ERP studies investigating the retrieval of such type of novel compounds (Bader et al., 2010; Wiegand et al., 2010) suggest that novel conceptual units and single items elicit different familiarity signals: absolute and relative familiarity. The aim of Experiment 2 was two-fold. The first aim was to compare the brain regions generally engaged in retrieval of experimentally unitized associations to those engaged in retrieval of arbitrary associations. The second aim was to compare brain regions which are involved in relative familiarity for single items and absolute familiarity for novel units.

By means of fMRI, the neural correlates of associative recognition memory were investigated when previously unrelated word pairs were unitized during encoding. Analogous to the previous ERP studies (Bader et al., 2010; Wiegand et al., 2010), I compared the neural correlates of associative recognition memory for unrelated German word pairs using encoding instruction as a between-group variable (see Figure 6.1). Unitization was stimulated in the definition group who learned word pairs together with a definition combining the two words to a novel conceptual unit. Conversely, unitization was minimized in the sentence group who studied the pairs together with a sentence frame containing the two words as distinct lexical items. Encoding instruction was manipulated between subjects to avoid any strategy carry over between the two instructions. After one long study block, participants had to do a surprise recognition test. Encoding was incidental in order to reduce the probability that participants apply individual encoding strategies which could obscure the intended effects of the instructions. During recognition, different types of word pairs were presented: same pairs reappeared in the same order as during study, reversed pairs consisted of studied pairings but in reversed order, recombined pairs were new combinations of two words studied within two different pairs, and new pairs consisted of two unstudied words. Same and reversed pairs had to be classified as 'old' whereas recombined and new pairs had to be classified as 'new'. Comparable to the Wiegand et al. (2010) study (see also Experiment 1), reversed pairs were included. The rationale behind this was that reversing

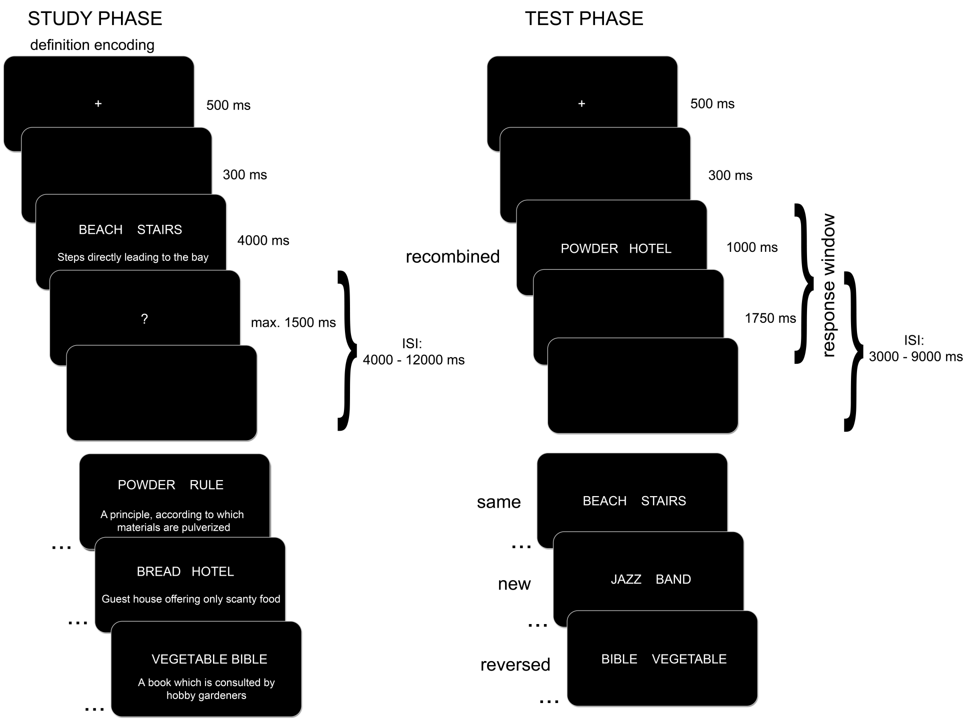


Figure 6.1.: Schematic illustration of the study phase in the definition group and the test phase in both groups. In the sentence group, the definitions were replaced by the respective sentences. In the study phase, participants judged the fit of the definition/sentence and the pair during the presentation of the question mark. In the test phase, participants had to discriminate between same, reversed, recombined, and new pairs before the end of the response window. Same and reversed pairs had to be classified as 'old' and recombined and new pairs had to be classified as 'new'.

the word pair disrupts the newly created unit as the exact configuration is a key feature of units (Haskins et al., 2008; Horowitz & Prytulak, 1969; Wiegand et al., 2010). Hence, the effects of unitization are assumed to be present for same pairs only, while pure item recognition mechanisms should be diagnostic for reversed pairs.

Due to the disruption of the novel units, I expected processing difficulties for reversed pairs being evident in decreased performance and longer reaction times compared to same pairs in the definition group. This was not expected for the sentence group in which no conceptual units were created. Here, recollection-driven processing should result in comparable performance for same and reversed pairs because recollection is assumed to be less reliant on the precise configuration, as findings from recall implicate (e.g., Kahana, 2002, see also Section 2.2.1 and Experiment 1). Generally, I expected recollection to be the main process

<table>
<tr><th colspan="2"></th><th colspan="4">definition encoding</th><th colspan="4">sentence encoding</th></tr>
<tr><th colspan="2"></th><th>sam</th><th>rev</th><th>rec</th><th>new</th><th>sam</th><th>rev</th><th>rec</th><th>new</th></tr>
<tr><td rowspan="3">retrieval processes</td><td>recollection</td><td>+</td><td>+</td><td></td><td></td><td>++</td><td>++</td><td></td><td></td></tr>
<tr><td>item familiarity</td><td>+</td><td>+</td><td>+</td><td></td><td>+</td><td>+</td><td>+</td><td></td></tr>
<tr><td>unit familiarity</td><td>++</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2" rowspan="3">process-specific contrasts</td><td colspan="4">unit familiarity
= same vs. reversed</td><td colspan="4" rowspan="2">recollection
= same vs. recombined
/ reversed vs. new</td></tr>
<tr><td colspan="4">item familiarity
= reversed vs. new</td></tr>
<tr><td colspan="8">general recognition
= same vs. new</td></tr>
</table>

Figure 6.2.: Schematic illustration of hypothesized primary retrieval processes in the two encoding groups and definition of process-specific contrasts. Note that for recollection, two contrasts are equally suitable to reveal process-specific brain regions, and that the reversed vs. new contrast is associated with different processes in the two groups. Thickness and number of crosses indicate relative importance of the process in the respective encoding group. sam = same; rev = reversed; rec = recombined.

to subserve associative recognition in the sentence group. In contrast, recollection should play a minor role in the definition group as reduced engagement of regions normally associated with recollection was already shown for pre-existing unitized pairs (Ford et al., 2010). Moreover, the finding of a reduced putative ERP correlate of recollection (Bader et al., 2010) suggests that a reduced involvement of the recollection network can be expected for novel conceptual units, too. Effects specific to unitization should only be present in the definition group and absent in the sentence group whereas relative familiarity signals should be observable in both groups. These general assumptions should become manifest in the following specific contrasts (see Figure 6.2).

At first, a general recognition memory contrast between correct responses to same and new pairs was examined because the former reflect recognized items in general irrespective of the involved process and the latter reflect a memory free baseline condition. For the sentence group, I expected activation in a network including the hippocampus and other regions normally associated with recollection such as the posterior cingulate cortex and the ventral PPC (e.g., Daselaar, Fleck, & Cabeza, 2006; Henson et al., 2005; Vilberg & Rugg, 2008; Yonelinas et al., 2005). In the definition group, the engagement of the recollection network was expected to be reduced. Moreover, this contrast should have the maximal potential to reveal all the brain structures involved in both hypothesized familiarity processes. Thus, I generally predicted deactivation in the PrC as well as activation in other regions previously associated with familiarity such as the lateral PFC (BA 45/46) and the dorsal PPC in the definition group (e.g., Daselaar, Fleck, & Cabeza, 2006; Henson et al., 2005; Montaldi et al., 2006; Vilberg & Rugg, 2008; Yonelinas et al., 2005; Aly et al., 2011).

The next contrast was intended to capture those regions which are specifically crucial for associative recognition memory comparing correct responses to same and recombined pairs as item familiarity should not be diagnostic to distinguish these pair types. In the sentence group, absolute familiarity should not be elicited. Therefore, this contrast was assumed to reveal again mostly regions associated with recollection (see above). In contrast, the engagement of this network was expected to be smaller in the definition group where, as in the same vs. new contrast, familiarity-related regions should be more engaged. These should be limited to regions involved in absolute familiarity (see below).

The contrast between correctly recognized reversed and new pairs should reveal brain regions involved in item recognition, especially in the defnition group where influences of recollection are assumed to be minimal. Moreover, reversed pairs are not assumed to evoke absolute familiarity because the unit is assumed to be disrupted. For this reason, they should be a more sensitive indicator of relative familiarity than same pairs when contrasted to new pairs.[1] Given that recollection is assumed to play a minor role in the definition group, the reversed vs. new contrast is expected to reveal mostly activity modulation in regions previously associated with familiarity. In particular, I predicted decreased activation for reversed compared to new pairs in the perirhinal cortex as this region is highly implicated in familiarity for single items (e.g., Henson et al., 2003; Montaldi et al., 2006). As the recollection-based processing in the

[1]Reversed pairs were chosen for this contrast because the requirement to classify recombined pairs as 'new' allows that not recognized unfamiliar recombined pairs are correctly rejected. This makes recombined pairs more heterogeneous in terms of familiarity and therefore less suitable for the item familiarity contrast.

sentence group should be flexible with respect to the order of the pair (Giovanello et al., 2009), the pattern of results in the sentence group was expected to be similar to the same vs. new contrast.

The effect of unitization is postulated for newly created unitized word pairs, only, i.e. for same pairs in the definition group. As the unit is assumed to be disrupted for reversed pairs and item familiarity should be equal for the two pair types, brain regions which are specific to recognition of novel conceptual units were determined by the same vs. reversed pairs contrast. Moreover, differences in recollection between same and reversed pairs should be negligible because both pair types had to be classified as 'old'. Due to the lack of previous studies, I did not have any specific expectations with respect to the localization of these regions. From the data reported by Haskins et al. (2008), a perirhinal familiarity signal should be expected for same in contrast to new pairs. However, it is unclear whether this is additional to the familiarity signal for the single items (in magnitude or spatial extent). In general, I predicted absolute familiarity regions to be revealed only in the definition group but not in the sentence group.

6.1 Methods

6.1.1 Participants

Forty native German speakers, all students from Saarland University, took part in the experiment and were randomly assigned to the two encoding groups. Mean age was 22.3 (range: 19–28) and 23.2 (range: 19–29) in the definition (10 male/10 female) and the sentence (10 male/10 female) encoding group, respectively. All participants had no known neurological problems, had normal or corrected-to-normal vision (contact lenses or fMRI compatible goggles) and were right-handed as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971). One additional participant took part, but had to be excluded because of excessive motion during scanning. The experiment was approved by the local ethics committee of Saarland University. Participants gave informed consent and were reimbursed with course credit or payment (8 Euros/hour) for participation.

6.1.2 Materials

Stimuli were built of 160 pairs of thematically and categorically unrelated German 3-10 letter nouns with a mean lexical frequency of 54/million (Baayen et al., 1995) (see Appendix A.3 for a full list of stimuli). Pairings had to fulfill the requirement of being suitable for compound combination in German in original and reversed order. To this end, some of the words were used in plural form. Original and reversed pairs did not differ according to frequency of plural words in first and second position. Unrelatedness of word pairs (in original and reversed order and all recombined pairs) was assured by a pre-experimental rating study (each word pair was rated by 16 participants on average who belonged to the same student population but did not participate in the actual experiment). For definition encoding, a definition combined each word pair to denote a novel concept (e.g., VEGETABLE BIBLE - A book which is consulted by hobby gardeners). Only synonyms or associates of the words were used in the definitions. Likewise, there were no repetitions of the words in the sentences for the sentence group. Here, the words were part of a sentence as separate lexical items but were substituted by blank spaces (e.g., VEGETABLE BIBLE – This ___ was already mentioned in the ___).

Study lists comprised 128 word pairs together with either the corresponding definitions or sentences. Of these pairs, 32 reappeared in the same combination and order as in the test phase. Another 32 were in the original combination but in reversed order. The remaining 64 were used to build 32 recombined pairs consisting of new combinations of studied words whereby only one word of each original pair was used. First and second positions of the single words were maintained from original to recombined pairs. Additional 32 word pairs served as new pairs. Assignment of word pairs to the 4 pair types (same, reversed, recombined, and new) was counterbalanced across participants.

6.1.3 Procedure

The experiment was presented using E-Prime Professional 2.0 (Psychology Software Tools, Inc.). The experiment consisted of three parts: a study phase, a motor response task in the retention interval, and a test phase. All three parts were run in the scanner. Participants responded via two 2-button response grips using their thumbs and index fingers of both hands. Participants were not aware of the final memory test.

Participants' head movements were minimized using cushions and a headrest. Stimuli were viewed through a mirror attached to the head coil on which they were projected via a translucent screen. All stimuli were presented in white on a black background. Word pairs were presented next to each other separated by four blanks. In the study phase, word pairs and definitions/sentences were displayed one above the other, slightly above and below the center of the screen. Sentence frames in the sentence group contained two blank spaces in which participants had to mentally insert the two words in the given order. In the test phase, word pairs were presented in central vision. Encoding group was manipulated between subjects. The definition group had to give a subjective rating 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 novel compound. To facilitate the rating, they were told to create a mental image of the new concept. In the sentence group, participants were supposed to rate the plausibility of the sentence on a 4-point-scale after having inserted the two words. To prevent unitization, participants were told to imagine each single object separately. Assignment of fingers and ratings was counterbalanced across subjects. In both encoding groups, a trial started with a 500 ms fixation cross followed by 300 ms blank screen. Then, the stimulus appeared on the screen for 4000 ms after which participants were given a 1500 ms response window for the rating judgment indicated by a question mark. The inter-stimulus interval (ISI) was jittered in steps of 1000 ms following an approximately exponential distribution (mean: 7000 ms, range: 4000 – 12000 ms). It included the response window and a blank screen. In the middle of the study phase, there was a break of 46.2 s. After the study phase, there was a retention interval of about 10 minutes containing a simple motor response task. Participants were then informed about the upcoming memory test. In the test phase, both encoding groups saw exactly the same stimuli and had the same task. Participants had to classify same and reversed pairs as 'old' and recombined and new pairs as 'new'. They were instructed to indicate if they were sure or unsure about their classification resulting in four possible responses. Mapping of responses and fingers was counterbalanced across subjects. Trials started with a 500 ms fixation cross followed by a 300 ms blank screen. Word pairs were presented for 1000 ms. The response window expanded additional 1750 ms with a blank screen. If participants failed to respond until then, they saw a warning 'Too slow!' for 500 ms. The ISI included the response window and the warning if applicable. The remaining time was filled with a blank screen. ISI duration was jittered in steps of 1000 ms following an approximated exponential distribution (mean: 4000 ms, range: 3000 – 9000 ms). In the middle of the test phase, there was a break of 46.2 s.

6.1.4 Data Acquisition and Processing

A Siemens Skyra 3T system was used for MRI data acquisition. For functional MR scans T2-weighted gradient-echo planar imaging sequences with blood oxygen level dependent (BOLD) contrast were used (Matrix: 94, FOV = 192 mm, TR = 2200 ms, TE = 30 ms, flip angle = 90°). Thirty axial slices with a thickness of 3 mm, an inter-slice gap of .75 mm, and an in-plane resolution of 2.04 × 2.04 mm were acquired parallel to the AC-PC plane covering the whole brain. In order to allow for T1 equilibration the first four volumes of each functional run were discarded. Prior to the experiment high resolution (.9 × .9 × .9 mm) T1-weighted anatomical brain scans (MP-RAGE) were obtained. In order to foster the co-registration of these anatomical images with the functional images, 3 mm thick T1-weighted images (TR = 250 ms, TE = 2.5 ms, flip angle = 70°, in-plane resolution of .6 × .6) in plane with the functional images were acquired. MRI data was processed using Brain Voyager QX (Brain Innovation; Goebel, Esposito, & Formisano, 2006). First, the 366 functional volumes of the test phase were slice acquisition time corrected to the beginning of each volume scan using cubic spline interpolation. Second, all images were motion corrected to the first volume of the run applying a trilinear detection and sinc interpolation rigid-body-transformation. Following spatial smoothing (Gaussian kernel with a full width at half maximum of 4 mm), low-frequency signal changes and baseline drifts were removed by a high-pass filter at .004 Hz. Transformation parameters gained by co-registration of functional and anatomical images were applied to the preprocessed fMR images to create a representation of the functional time series in 3D space which was subsequently normalized into stereotactic Talairach space (Talairach & Tournoux, 1988) and re-sampled to a resolution of 2 × 2 × 2 mm.

6.1.5 Data analysis

Only data of the test phase was analyzed. Behavioral data was analyzed using SPSS 18. Accuracy as indicated by the percentage of correctly classified items and reaction times for correct items were entered into a

Pair Type (same, reversed, recombined, new) × Encoding Group (definition, sentence) multivariate analysis of variance (MANOVA, Pillai's trace) with the within-subjects factor of Pair Type and the between-subjects factor of Encoding Group. Proportion of high confidence judgments of correct items was analyzed in a Confidence (high, low) × Encoding Group (definition, sentence) MANOVA. The significance level of the aforementioned analyses was set to $\alpha = .05$. P-values in post-hoc comparisons were corrected for Type-I-error accumulation using Holm's sequential Bonferroni correction method (Holm, 1979).

Statistical analysis of the fMRI was conducted using BrainVoyager QX (Brain Innovation; Goebel et al., 2006). The functional time series were analyzed with least-squares estimation using a mixed effects general linear model. The event-related design matrix was created by modeling the hemodynamic response function for each predictor using a box-car function with a 1 s event duration convolved with a 2-gamma function model (onset: 0, time to response peak: 5 s, time to undershoot peak: 15 s) starting at the onset of the critical events. Correctly responded to items were used to build four levels of Pair Type which entered the general linear model as predictors (same, reversed, recombined, new). All incorrectly classified items, key presses as well as 3-D motion parameters estimated during motion correction were added as predictors of no interest. Percent signal change was calculated relative to a baseline based on the average of all non-modeled time points. Second-level analysis determined active clusters for four contrasts of interest (Figure 6.2). Generally, clusters of voxels were considered as active when the t-test for the contrast exceeded a threshold of $p < .001$ for at least 10 contiguous voxels (see Lieberman & Cunningham, 2009, for arguments in favor of using a voxel extent threshold). In the MTL, the threshold was set to $p < .005$ for at least 5 contiguous voxels.

In order to get an overview of the regions being generally involved in recognition of the word pairs, I first examined the contrast same vs. new pairs. Regions specifically involved in associative memory were identified by contrasting correctly identified same and recombined pairs. Item recognition regions were defined as regions which were more active for reversed than for new pairs. Brain regions specific to unitization effects were determined by the same vs. reversed pairs contrast. For all three contrasts, three different analyses were conducted to disentangle effects specific and common for the two groups. Common group effects were revealed by a conjunction analysis identifying the overlap between active regions in both groups (Friston, Penny, & Glaser, 2005). Group specific effects for one of the groups were identified by masking active regions in the other group. Exclusion masks were thresholded at a liberal threshold of $p < .05$ in order to reduce the probability of missing a truly active region. Note that a liberal threshold in the exclusion mask is equivalent to a conservative procedure to detect group specific effects (see Desseilles et al., 2009; Uncapher, Otten, & Rugg, 2006, for a similar rationale).

6.2 Results

6.2.1 Behavioral Results

As can be seen in Figure 6.3, performance in the sentence group seemed to be generally better than in the definition group. MANOVA of accuracy as indicated by percentage of correctly classified items with the factors Pair Type and Encoding Group revealed a significant main effect of Pair Type ($F(3, 36) = 67.07, p < .001$), a significant main effect of Encoding Group ($F(1, 38) = 6.30, p < .05$), and a marginally significant interaction ($F(3, 36) = 2.75, p < .06$). Dissolving the interaction, post-hoc comparisons between encoding groups for each pair type separately yielded only one significant difference, namely higher accuracy for reversed pairs in the sentence group ($M = .80, SE = .12$) than in the definition group ($M = .68, SE = .10; t(38) = 3.48, p < .01$). Comparisons of same pairs (definition: $M = .80, SE = .11$; sentence: $M = .83, SE = .09$), recombined pairs (definition: $M = .74, SE = .15$; sentence: $M = .79, SE = .13$), and new pairs (definition: $M = .94, SE = .06$; sentence: $M = .95, SE = .08$) across encoding groups were not significant (*p-values* $> .62$). These results show that the overall difference is mainly driven by the higher performance for reversed pairs in the sentence group. Furthermore, testing my specific hypotheses regarding accuracy for same pairs and reversed pairs, planned t-tests revealed that reversed pairs were remembered significantly worse than same pairs in the definition group ($t(19) = 4.22, p < .001$), but not in the sentence group ($p > .27$) suggesting processing difficulties for disrupted units in the definition group. The proportion of time-outs was low for the definition group (same: 0, reversed: .002, recombined: .009, new: .006) and the sentence group (same: .003, reversed: 0, recombined: .002, new: .003) and did not differ between the groups ($p > .19$).

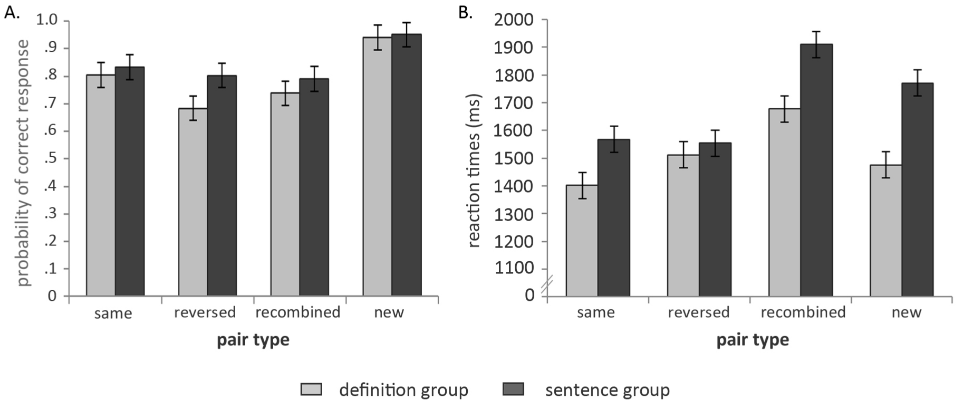


Figure 6.3.: Mean probabilities of correct responses (A.) and mean reaction times (B.) for same, reversed, recombined, and new pairs in the definition and sentence encoding group in Experiment 2. Error bars indicate 95% confidence intervals for the interaction term (Jarmasz & Hollands, 2009).

A general speed advantage for the definition group (see Figure 6.3) was demonstrated by a MANOVA of reaction times (Pair Type × Encoding Group) revealing a significant main effect of Pair Type ($F(3,36) = 60.59, p < .001$), a significant main effect of Encoding Group ($F(1,38) = 6.26, p < .05$), and a significant interaction ($F(3,36) = 8.84, p < .001$). Post-hoc t-tests showed faster reaction times in the definition group than in the sentence group, which were significantly different for recombined pairs (definition: $M = 1677, SE = 72$; sentence: $M = 1910, SE = 52$; $t(38) = 2.62, p < .05$) and for new pairs (definition: $M = 1476, SE = 66$; sentence: $M = 1770, SE = 52$; $t(38) = 3.51, p < .01$) and marginally significantly different for same pairs (definition: $M = 1401, SE = 53$; sentence: $M = 1567, SE = 49$; $t(38) = 2.26, p < .06$). No differences were obtained for reversed pairs (definition: $M = 1512, SE = 56$; sentence: $M = 1554, SE = 41; p < .55$) suggesting that even though recognition judgments are speeded up after definition encoding, this is not the case when reversed pairs serve as retrieval cues. With regard to my hypotheses for the comparison between same and reversed pairs, t-tests revealed that same pairs were recognized faster than reversed pairs in the definition group ($t(19) = 4.56, p < .001$), but not in the sentence group ($p > .48$) further underlining the importance of the exact configuration for unitized pairs.

The proportion of high confidence judgments of all correct responses shows that participants in both groups were highly confident, but consistently higher in the sentence group than in the definition group for same pairs (definition: $M = .85, SE = .03$; sentence: $M = .93, SE = .02$), reversed pairs (definition: $M = .80; SE = .05$, sentence: $M = .94, SE = .02$), recombined pairs (definition: $M = .56, SE = .05$; sentence: $M = .68, SE = .06$), and new pairs (definition: $M = .63, SE = .05$; sentence: $M = .68, SE = .06$). A Pair Type × Encoding Group MANOVA yielded a significant main effect of Pair Type ($F(3, 36) = 22.54, p < .001$) and of Encoding Group ($F(1, 38) = 4.31, p < .05$) the latter reflecting participants' higher confidence in the sentence group than in the definition group. The interaction did not reach significance ($p > .19$). Post-hoc t-tests revealed that 'old' responses were generally given with higher confidence than 'new' responses irrespective of encoding group: same vs. recombined ($t(39) = 8.41, p < .001$), same vs. new ($t(39) = 6.19, p < .001$), reversed vs. recombined ($t(39) = 6.71, p < .001$), reversed vs. new ($t(39) = 4.98, p < .001$). All other comparisons were not significant (*p-values* $> .27$). Thus, recognition of word pairs studied within sentence frames was accomplished with higher confidence. Moreover, confidence in recognizing studied pairs was higher than in rejecting non-studied pairs.

6.2.2 Imaging Results

Same vs. New Pairs: General Recognition Memory

In order to see the general pattern of active regions underlying successful recognition judgments in this associative recognition memory task, active regions contrasting same vs. new pairs were explored. The results are listed in Table 6.1. Activated clusters common to both groups were found on the left medial and lateral surface of the parietal lobe. Specifically in the sentence group, activation on the medial surface was generally more extended (Figure 6.5.A) and the activation in the PPC reached further ventral (Figure 6.4.A). Additionally, there were activated clusters in the left middle frontal gyrus and in a region at the boarder of the left hippocampus and entorhinal cortex (Figure 6.6.A). In the definition group, the activation in the PPC spread further dorsal and medial (Figure 6.4.A). No clusters were identified in the new > same contrast.

Same vs. Recombined Pairs: Recollection

In order to identify regions specific to recollection which should predominantly be activated in the sentence group, same and recombined pairs were compared. As listed in Table 6.2, whole brain analysis revealed common activation in regions on the medial surfaces of the PFC and the

Table 6.1.: Brain regions showing significantly different BOLD signals for **same vs. new** *pairs. Side of activation (Hemi; L = left, R = right, B = bilateral), Brodmann areas (BA), size of activation (in anatomical voxels), Talairach coordinates of peak voxels (for group-specific clusters) or center of gravity (for inclusion analysis), and t-value of peak voxel are indicated. Note that there is no peak voxel in a conjunction analysis.*

region of activity	**hemi**	**BA**	**size**	**x**	**y**	**z**	**t-value**
both groups							
same > new							
Posterior Cingulate	L	31	520	-5	-46	27	
Inferior Parietal Lobule	L	40	88	-41	-56	37	
Angular Gyrus	L	39	136	-50	-60	32	
Angular Gyrus	L	39	416	-42	-68	32	
same < new							
no clusters							
sentence group							
same > new							
Middle Frontal Gyrus	L	6	141	-39	1	45	4.97
Posterior Cingulate	L	31	226	-13	-48	26	5.23
Posterior Cingulate	L	29	703	-4	-48	14	6.34
Inferior Parietal Lobule	L	40	169	-51	-58	39	5.57
Middle Temporal Gyrus	L	39	1605	-48	-57	23	7.61
Superior Occipital Gyrus	L	19	171	-36	-75	27	5.08
Superior Occipital Gyrus	L	19	117	-39	-79	27	5.29
Hippocampus / Entorhinal Cortex	L	28	89	-18	-22	-13	3.80
same < new							
no clusters							
definition group							
same > new							
Precuneus	L	19	139	-32	-71	35	5.85
Inferior Parietal Lobule	L	40	168	-40	-52	43	5.31
same < new							
no clusters							

parietal lobe (Figure 6.5.B). As in the same vs. new contrast, there was recruitment of the hippocampus (Figure 6.6.B), the posterior cingulate and the ventral PPC (Figure 6.4.B) in the sentence group. In addition, there were activated clusters in bilateral superior frontal gyrus. Specific to the definition group was an anterior extension of the common activation in the anterior cingulate (Figure 6.5.B). Clusters showing a higher activation for recombined than same pairs were not revealed.

Table 6.2.: Brain regions showing significantly different BOLD signals for **same vs. recombined** *pairs. See Table 6.1 for details.*

region of activity	**hemi**	**BA**	**size**	**x**	**y**	**z**	**t-value**
both groups							
same > recombined							
Medial Frontal Gyrus	L	10	144	-7	50	15	
Anterior Cingulate	L	24	88	-2	38	3	
Posterior Cingulate	L	23	80	-2	-49	25	
same < recombined							
no clusters							
sentence group							
same > recombined							
Superior Frontal Gyrus	R	8	85	9	51	38	4.83
Superior Frontal Gyrus	L	8	122	-15	34	51	5.28
Superior Frontal Gyrus	R	6	115	15	20	59	6.08
Superior Frontal Gyrus	L	6	124	-10	25	58	5.69
Anterior Cingulate	L	32	262	-5	34	19	6.79
Anterior Cingulate	B	24	163	0	35	6	6.42
Cingulate Gyrus	B	31	122	1	-23	39	4.96
Cingulate Gyrus	B	23	139	0	-25	30	5.29
Cingulate Gyrus	B	31	317	-4	-28	35	5.27
Posterior Cingulate	R	31	256	10	-47	26	5.87
Posterior Cingulate	B	30	1133	-5	-52	14	6.52
Inferior Parietal Lobule	R	40	381	46	-51	36	5.39
Inferior Parietal Lobule	L	40	128	-49	-58	39	5.38
Superior Temporal Gyrus	L	39	1178	-57	-60	18	7.15
Hippocampus	L		144	-24	-9	-20	4.37
same < recombined							
no clusters							
definition group							
same > recombined							
Anterior Cingulate	L	32	234	-3	44	7	5.98
same < recombined							
no clusters							

Reversed vs. New Pairs: Relative Familiarity and/or Recollection

The results of the reversed vs. new pairs contrast are listed in Table 6.3. There was common activation for reversed > new pairs in the left PPC (Figure 6.4.C). This spread more ventral in the sentence group. Additionally, there was activation specific for the sentence group in the left middle frontal gyrus, the left medial surfaces of the PFC and the parietal lobe (Figure 6.5.C) as well as the left hippocampus (Figure 6.6.B

Table 6.3.: Brain regions showing significantly different BOLD signals for **reversed vs. new pairs**. *See Table 6.1 for details.*

region of activity	hemi	BA	size	x	y	z	t-value
both groups							
reversed > new							
Angular Gyrus	L	39	182	-42	-64	35	
reversed < new							
no clusters							
sentence group							
reversed > new							
Middle Frontal Gyrus	L	6	285	-22	14	60	6.14
Medial Frontal Gyrus	L	9	173	-5	38	32	6.36
Medial Frontal Gyrus	L	9	198	-9	30	31	5.81
Medial Frontal Gyrus	L	9	83	-3	52	18	5.26
Anterior Cingulate	L	32	99	-8	34	24	5.18
Thalamus	L		161	-4	-15	10	6.35
Posterior Cingulate	R	23	146	10	-48	24	5.62
Posterior Cingulate	L	31	1895	-11	-56	20	7.41
Middle Temporal Gyrus	L	19	3927	-37	-77	21	7.57
Hippocampus	L		169	-22	-19	-12	4.85
Amygdala	L		70	15	-7	-9	4.88
reversed < new							
no clusters							
definition group							
reversed > new							
Inferior Frontal Gyrus	L	45	203	-48	23	19	5.75
Inferior Parietal Lobule	L	39	684	-36	-64	41	6.70
Caudate Nucleus	L		83	-9	3	9	4.91
reversed < new							
no clusters							

and C). Regions exclusively activated in the definition group were found in the left IFG (BA 45) and in a more dorsal and more medial extension of the common activation in the posterior parietal lobe (Figure 6.4.C).

Same vs. Reversed Pairs: Absolute Familiarity

In search for regions specific to unitization, same and reversed pairs were contrasted. There was no cluster being more activated by same than reversed pairs neither was there one being more activated by reversed than same pairs.

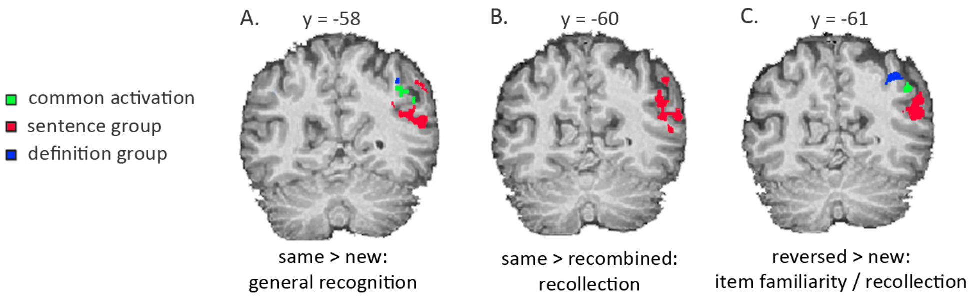


Figure 6.4.: Common and group-specific activation in clusters on the lateral surface of the left hemisphere activated by three different contrasts. The clusters are overlaid on a T1-weighted image of one participant and coordinates indicate slice position. Note that left hemisphere is depicted on the right side.

Absolute vs. Relative Familiarity

Although predicted, the same vs. reversed contrast did not reveal any clusters specific to absolute familiarity. However, different patterns of results in the same > new (general recognition) and the same > recombined contrast in comparison to the reversed > new (relative familiarity)

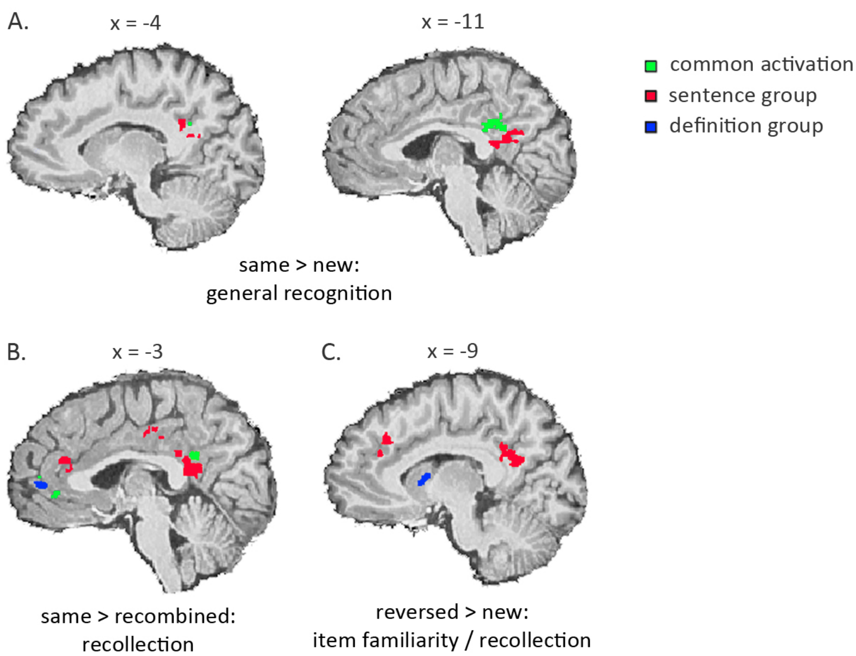


Figure 6.5.: Common and group-specific activation in clusters on the medial surface of the left hemisphere activated by three different contrasts. The clusters are overlaid on a T1-weighted image of one participant and coordinates indicate slice position.

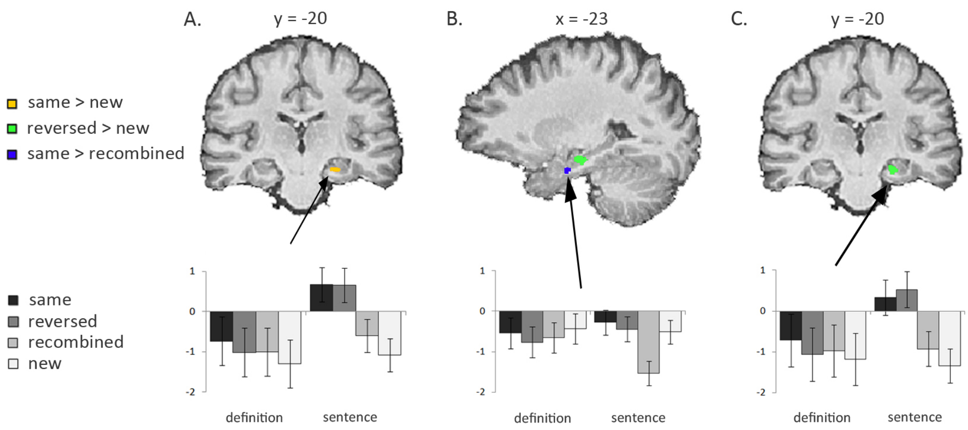


Figure 6.6.: Common and group specific activation in clusters in the hippocampus activated by three different contrasts in the left hemisphere (upper panel). The clusters are overlaid on a T1-weighted image of one participant and coordinates indicate slice position. Note that left hemisphere is depicted on the right side. For descriptive purpose, bar graphs show mean beta values in the indicated clusters for all four pair types (lower panel) in both encoding groups. Error bars indicate standard errors of the mean.

contrast in the definition group suggest that there are differences in the processing of same and reversed pairs which might not have been revealed by the same vs. reversed contrast. Therefore, I conducted two additional analyses for the definition group which might be more sensitive to detect regions specific to absolute and relative familiarity.

In order to isolate absolute familiarity regions, the same > new contrast was masked by the reversed > new contrast (exclusive mask thresholded at $p > .05$). Thus, this analysis reveals regions which are activated by

Table 6.4.: Brain regions which were selectively activated for **same > new** *and* **reversed > new** *in the definition group. In this analysis, each contrast was exclusively masked by the other contrast. See Table 6.1 for details.*

region of activity	**hemi**	**BA**	**size**	**x**	**y**	**z**	**t-value**
same > new masked by reversed > new							
Medial Frontal Gyrus	L	10	80	-12	51	7	6.61
Posterior Cingulate	L	31	112	-10	-50	22	5.34
Precuneus	L	7	96	-4	-59	31	5.97
Middle Temporal Gyrus	L	39	176	-41	-70	28	5.24
reversed > new masked by same > new							
Inferior Frontal Gyrus	L	45	96	-44	19	12	4.87

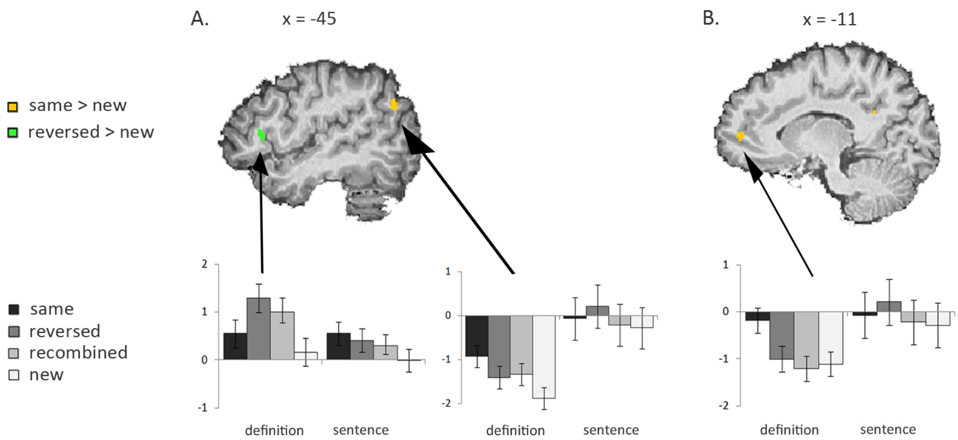


Figure 6.7.: Selected clusters in the left hemisphere which were selectively activated for same > new and reversed > new, respectively, in the definition group (upper panel). In this analysis, each contrast was exclusively masked by the other contrast. The clusters are overlaid on a T1-weighted image of one participant and coordinates indicate slice position. For descriptive purpose, bar graphs show mean beta values in the indicated clusters for all four pair types (lower panel) in both encoding groups. Error bars indicate standard errors of the mean.

same pairs in contrast to new pairs, but not for reversed pairs in contrast to new pairs. Activated clusters were found on the medial surface of the PFC and the parietal lobe as well as in the left PPC (Table 6.4 and Figure 6.7.A and B).

In order to identify regions specific to relative familiarity, the reversed > new contrast was masked by the same > new contrast. This analysis revealed regions which show greater activation for the reversed compared to new pairs but not for same compared to new pairs. Only one cluster in the left IFG was found (BA 45) to be activated in this analysis (see Table 6.4 and Figure 6.4.A).

6.3 Discussion

The current study compared neural activity during associative retrieval for unrelated word pairs which were either encoded in a unitized or in a non-unitized manner. The aim of the experiment was to find out which brain regions are generally involved in retrieval of unrelated word pairs when they have been unitized in only one study trial compared to non-unitized word pairs. Moreover, the design of Experiment 2 allowed to directly compare brain regions associated with absolute familiarity for novel units to those associated with relative familiarity for single items within one experiment. Unitization was manipulated between subjects. In the definition group, participants encoded word pairs together with a definition combining the two words to a novel conceptual unit. In the sentence group, participants were provided with a sentence frame in which they had to fill in the two words of the pair separately minimizing the degree of unitization. At test, participants had to discriminate same, reversed, and recombined versions of the studied pairs as well as completely new pairs.

6.3.1 Behavioral Data

Assessment of behavioral data revealed that participants in the two groups generally performed on the same level, but differed according to how well they could deal with reversed pairs. Consistent with my assumption, the definition group recognized reversed pairs significantly worse than the sentence group. This is in line with a less flexible retrieval process which is engaged after definition encoding where participants primarily rely on a familiarity signal for novel conceptual units. This unit familiarity signal is sensitive to the exact configuration of the pair and is disrupted by reversed test cues. Thus, the missing unit familiarity signal presumably makes the participants falsely rejecting the reversed pairs. Also consistent with greater reliance on familiarity in the definition group was the speed advantage for the definition group which was found for all except for reversed pairs. Within-group comparisons between same and reversed pairs complement this pattern. Decreased performance and slower reaction times for recognition of reversed pairs compared to same pairs was shown only in the definition group, but not in the sentence group. In the case of reversed pairs, participants in the definition group probably perceive interference when item familiarity indicates that the two items are old but missing unit familiarity indicates that the pair is new. This interference might also make participants reversing the presented test cue mentally in order to compare it to the studied pairs in mind which would also lead to prolonged response times. In line with the hypothesis of a reduced reliance on recollection for unitized word pairs is the lower confidence with which participants gave their responses because recollection based responses are thought to be associated with on average higher confidence (see Yonelinas, 2002).

6.3.2 Imaging Data

Analyses of the sentence group revealed a general pattern showing greater activation for studied pairs (same or reversed) in contrast to non-studied pairs (recombined or new) in areas located in the posterior cingulate, the ventral PPC, and the hippocampus. Activation in these brain regions was more extended in the sentence group than in the definition group or even exclusive as in the case of the hippocampus. These regions were previously identified as being associated with recollective processing (e.g., Henson et al., 2005, 1999; Yonelinas et al., 2005). Thus, these results are in line with the prediction that associative recognition of word pairs recruits a network typically associated with recollection when word pairs were studied as separate lexical items within sentence frames. Joining the few examples of fMRI studies examining the retrieval phase of associative recognition memory for arbitrary associations (e.g., Giovanello et al., 2004, 2009; Ford et al., 2010), the current experiment provides further evidence that in healthy young participants recognition of arbitrary word pairs strongly engages the recollection network including the hippocampus.

Complementing the behavioral results, this pattern of brain activation is in line with a flexible recollection process. Although encoded in a specific order (word order in the sentence), a highly overlapping network of brain regions is engaged when same and reversed pairs have to be retrieved. This is consistent with findings from recall implicating that recollection is less reliant on the precise configuration of the association (e.g., Kahana, 2002). I am aware of only one other fMRI study showing flexibility of the hippocampus with respect to order of the association (Giovanello et al., 2009). Interestingly, Giovanello et al. (2009) showed comparable activation for same and reversed pairs only in the anterior but not in the posterior hippocampus. As can be seen in Figure 6.6.A and 6.6.C, the clusters identified in the same vs. new and the reversed vs. new contrast are almost at the same location in the anterior hippocampus. Thus, the current study substantiates the notion that the anterior hippocampus can retrieve associations in a highly flexible way. The same vs. recombined contrast revealed a non-overlapping cluster even further anterior which seems to be selectively deactivated for recombined pairs (see Figure 6.6.B) exhibiting a similar activation level for same, reversed, and new pairs. At first glance, this pattern seems difficult to explain. If one assumes that activation in this cluster is associated with successful associative memory, one would expect the new pairs to show a level of activation which is similar to recombined pairs. However, the anterior hippocampus has also been associated with novelty detection for single items (e.g., Daselaar, Fleck, & Cabeza, 2006). Thus, it is possible that activation related to the novelty of the new pairs countervailed the effects of associative memory. Although the exact functional interpretation of this finding remains elusive, Experiment 2 extends the findings by Giovanello et al. (2009) showing flexibility also for other regions in the recollection network such as the posterior cingulate and the ventral PPC.

In the definition group, greater activation for same than new pairs in the posterior cingulate and the PPC was found mainly in areas overlapping with the sentence group. This suggests at least some residual recollection in the definition group. However, the extent of the activation was considerably smaller than in the sentence group and there was no hint of an involvement of the hippocampus. Notably, recollection-related activation in the definition group was primarily found when same pairs were presented as test cues (there was only one common cluster showing greater activation for reversed than new pairs in the angular gyrus). Thus, recollection in the definition group was dependent on the exact reinstatement of the study cue. This speaks in favor of successful integration during encoding and a less flexible process than in the sentence group which corresponds well with the impaired performance for reversed pairs in the definition group. In sum, these results imply a minimal impact of recollection when word pairs have been unitized in contrast to non-unitized word pairs. Although evidence for reduced recollection for unitized associations has been reported before in ERP (Bader et al., 2010; Jäger et al., 2006) as well as fMRI studies (Ford et al., 2010), this finding has until now received only little attention. Reduced recollection for unitized representations could reflect that more effortful recollective retrieval processes are less recruited if familiarity provides a sufficiently diagnostic signal. Note that some ERP studies did not find evidence for reduced recollection for unitized associations when study conditions promoted the contribution of recollection. For example in the Wiegand et al. (2010) study, all word pairs were studied twice, a condition which is known to increase recollection (Jacoby et al., 1998; Opitz, 2010a) while in the Rhodes and Donaldson studies (2007, 2008b) multiple short study-test-cycles were used. The exact boundary conditions of when unitization influences recollection still have to be determined.

In addition to the common activation in the PPC, activation extended into more ventral areas in the sentence group (for same > new, same > recombined, and reversed > new). In contrast, activation spread more dorsal and medial into the vicinity of the intra-parietal sulcus in the definition group (for same > new and reversed > new). This corresponds to a dissociation which has previously been reported associating ventral PPC regions with recollection and more dorsal areas with familiarity (Yonelinas et al., 2005; Henson et al., 2005; Vilberg & Rugg, 2008). Although the dorsal area has often been associated with familiarity-based responses, there are doubts about the memory-specificity of its function (Vilberg & Rugg, 2008). However, irrespective of the exact functional interpretation, the differential activation patterns across the sub-regions of the PPC suggest stronger reliance on recollection in the sentence group and more familiarity-based responding in the definition group. This familiarity-related processing seems to be general and neither specific to relative nor to absolute familiarity.

One region in the left IFG (BA 45) was more activated for reversed than new pairs selectively in the definition group. Additionally, this region was identified as specific to relative familiarity (rev > new masked by same > new). This region has previously been associated with familiarity-based retrieval. It has been shown to vary linearly with familiarity strength (Yonelinas et al., 2005) and damage to this regions leads to a selective deficit in familiarity (Aly et al., 2011). Aly and colleagues suggested a possible role of this region in setting decision criteria and/or assessing familiarity strength in order to make old/new judgments. This is further evidence that there was a tendency to base decisions on familiarity signals in the definition group. Moreover, it was shown that a cluster within this region was selectively activated by the reversed vs. new contrast and not by the same vs. new contrast suggesting a specific role of this region in relative familiarity. It is possible that the left IFG, as one of the possible generators of the mid-frontal old/new effect (see Bridger et al., 2012, for a discussion), is involved in the assessment of the increment in familiarity relative to a pre-experimental baseline (Stenberg et al., 2009). An alternative explanation for this activation pattern, however, could be that it reflects stronger engagement during the specification of the retrieval cue (Dobbins, Foley, Schacter, & Wagner, 2002). Cue specification might be more demanding for reversed pairs when participants choose the strategy to mentally reverse the test cue whenever they do not immediately recognize it as 'old' or 'new'. Although I cannot completely rule out this explanation, I think it is unlikely that participants consistently employed this strategy as in this case performance for reversed pairs should be much better.

The contrast between same and reversed pairs did not reveal any differences in activation between the two types of pairs. It is conceivable that the differences in brain activation for the two types of familiarity are too subtle to be detected by this contrast. The situation is even changed for the worse by a less optimal signal-to-noise ratio for the reversed pairs due to the poor performance for this pair type in the definition group. Moreover, if participants mentally reversed the test cue in the case of reversed pairs (even if only sometimes), the differences between same and reversed pairs become even more marginal. However, an additional analysis revealed brain regions which were selectively activated in the same vs. new contrast, but not in the reversed vs. new contrast. One of these clusters is located in the left PPC slightly inferior to the clusters which were shown to be selectively activated in the definition group compared to the sentence group (Figure 6.4.A). Thus, it probably reflects the enhanced recollection for same in contrast to reversed pairs already observed in the other contrasts. Two other clusters were identified on the medial surface of the parietal lobe. However, both of them were not revealed in the group comparison and are commonly either associated with recollection or both, recollection and familiarity. Thus, they do not seem to be specific to the same pairs in the definition group.

However, another region specific to the same vs. new contrast was found in BA 10 in the medial PFC. Consistently, this region was also activated in the same > recombined contrast in the definition group.[2] According to van Kesteren, Ruiter, Fernández, and Henson (2012), the mPFC is activated when incoming information is congruent to prior knowledge. If this is the case, mPFC couples with posterior association areas and inhibits hippocampal memory function. Thus, congruent events are encoded and retrieved by the neocortex whereas incongruent events (such as arbitrary associations) are encoded and retrieved by the hippocampus. Possibly, by providing a reasonable definition, unitization renders arbitrary word pairs more congruent to existing schemas leading to activation in mPFC. The lack of hippocampal activation for unitized pairs is consistent with this explanation.

[2]BA 10 was not revealed as specific for the definition group in the same vs. new contrast in the group comparison. However, a cluster in this region was obtained when reducing the voxel extent threshold to 5 contiguous voxels.

Familiarity signals in the PrC were not detectable in neither of the computed contrasts.[3] One possible reason of this null finding is that fMRI signals in the MTL can suffer from susceptibility-induced signal loss (e.g., Asano, Mihara, Kirino, & Sugishita, 2004) leading to a poor signal-to-noise ratio. Thus, it was impossible to find out whether there is activity modulation in the PrC associated with absolute familiarity which is additional to the item-related familiarity signal.

Experiment 2 showed that recognition of arbitrary associations encoded within sentence frames, which was supposed to minimize unitization, recruits a network of brain regions that has previously been associated with recollection. This underlines the importance of recollection in memory for arbitrary associations. Moreover, large parts of this network were shown to be highly flexible with respect to the order of the retrieval cue. Concordantly, memory performance for reversed pairs was comparable to same pairs in the sentence group. In contrast, using unitization as an encoding strategy as in the definition group leads to a limited involvement of this network. Consistent with this, I found faster reaction times and less confident responses in the definition group. This suggests that effortful recollection is recruited only if it yields additional diagnostic value for an associative memory task. Possibly, this is already determined during encoding which is why recollection could not be recruited for reversed pairs during the test although it would have been advantageous. There was a general shift to an engagement of brain regions previously associated with familiarity in the definition group such as BA 45 in the IFG or the dorsal part of the PPC. Contrary to my expectations, this shift was also observed for reversed pairs suggesting a generally greater emphasis on familiarity-based processing, not only for the intact conceptual units. Although, a clear dissociation of brain regions involved in item and unit familiarity was not revealed, an additional set of analyses suggests that activation in BA 45 was specific to reversed pairs, possibly associated with relative familiarity. In contrast, activation in BA 10 in the medial PFC was selective for same pairs and is possibly related to absolute familiarity.

[3]This null result is also obtained without the masking procedure.

CHAPTER 7

Experiment 3

7.1 Introduction

The findings summarized in Chapter 3 suggest that there are at least two different neural signals contributing to the feeling of familiarity: relative and absolute or conceptually-driven familiarity. Together with studies using pre-existing single items (e.g. Stenberg et al., 2009), the study by Wiegand et al. (2010) suggests that the early mid-frontal old/new effect is a marker of relative familiarity that operates on pre-existing representations in semantic memory. In contrast, the early parietal old/new effect in the same time window seems to be associated with absolute familiarity which takes effect in case of novel representations or when facilitated conceptual processing can be diagnostic for prior occurrence. According to the discrepancy-attribution-hypothesis (e.g., Whittlesea & Williams, 2001b, 2001a), this is the case whenever fluent processing occurs unexpectedly.

Applied to the influence of unitization on familiarity-based associative recognition memory (see Figure 4.1), relative familiarity seems to play a role when the to-be-remembered associates are already linked to one single representation. In support of this view, Rhodes and Donaldson (2007) found an enhanced mid-frontal old/new effect for associated word pairs such as *traffic–jam* in contrast to non-unitized word pairs. The pairs employed by Rhodes and Donaldson (2007) are perceived as unitized because together they denote one pre-experimentally known single concept. Unrelated pairs are pre-experimentally associated with two distinct concepts but can be unitized during study. Associative recognition of this kind of pairs was shown to be associated with an early parietal old/new effect (Bader et al., 2010; Wiegand et al., 2010). Moreover, consistent with the discrepancy-attribution-hypothesis, in these experiments the creation of novel units enhanced processing fluency for the pairs (a claim which was substantiated by Experiment 1 and 2). As fluent conceptual processing is unexpected for novel units because of their pre-experimental unrelatedness, it is conceivable to link the early parietal old/new effect to absolute familiarity.

The study by Rhodes and Donaldson (2007) on the one hand and the studies investigating recognition memory for novel units (Bader et al., 2010; Wiegand et al., 2010) on the other hand found the two different ERP effects across different experimental settings. Moreover, the study by Wiegand et al. (2010) dissociated the two ERP old/new effects by contrasting item and associative memory. Thus, the main aim of the current study was to dissociate the mid-frontal and parietal early old/new effect within one study by comparing two kinds of stimuli which are structurally comparable but differ in type of unitization. For this purpose, pre-experimentally unitized associations (compound pairs) were directly compared with experimentally unitized word pairs (novel units). Importantly, pre-experimentally existing compound pairs and experimentally learned novel units are both supposed to be conceptually integrated and therefore can be processed fluently during a recognition test. However, only for novel units this fluent processing is unexpected and therefore should elicit absolute familiarity. By using these two types of pairs, the potential confound of a study cue repetition only for one but not the other condition was avoided (see Experiment 1 for discussion). In the current experiment, old pairs of both conditions were exact repetitions of the study cue.

The notion that the early parietal old/new effect reflects differences in conceptual fluency for studied and unstudied items is motivated by its resemblance to the N400 effect. Among other processes, the N400 is considered to reflect the ease of semantic processing and has mostly been reported in language comprehension paradigms (Kutas & Federmeier, 2000, 2011). In those studies, processing ease is not directly task relevant but can be observed as a byproduct. Thus, the N400 can be considered as a marker of implicit memory access. Hence, if the early parietal old/new effect is an instantiation of the generic N400 effect under explicit memory conditions, it should also be observable outside the context of an explicit recognition memory experiment. This hypothesis underlies the second aim of the current experiment.

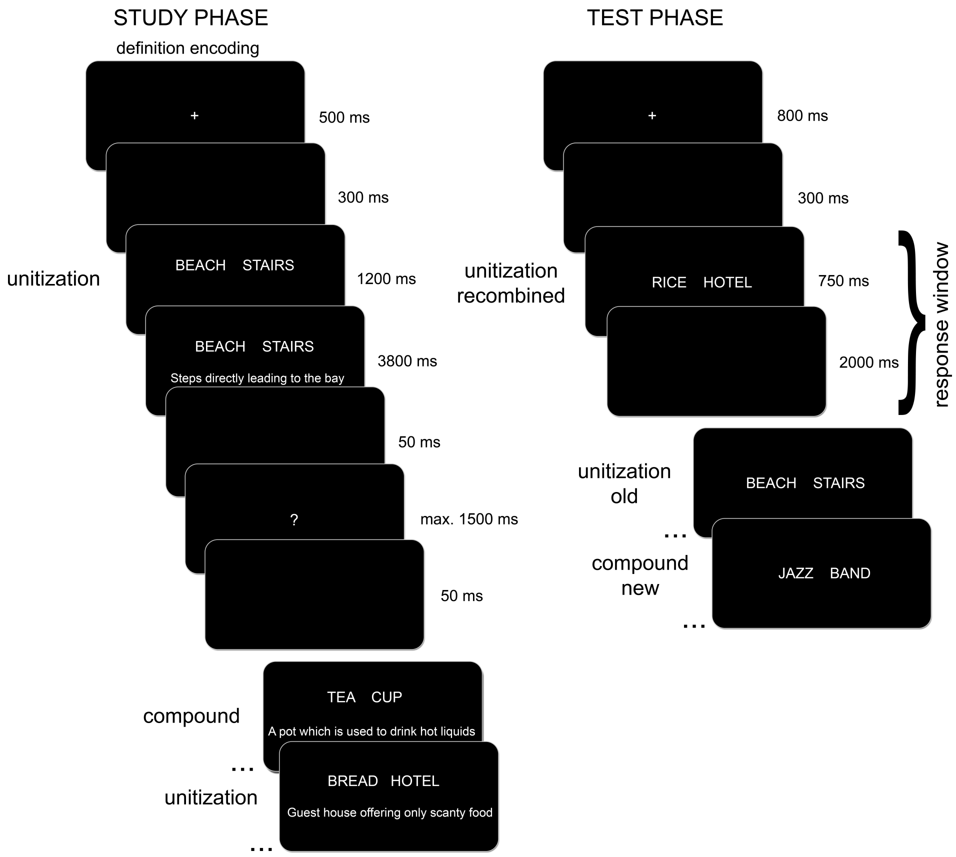


Figure 7.1.: Schematic illustration of one study-test block. Word pairs from both conditions were presented intermixed during study and test. In the study phase, participants judged the fit of the definition/description and the pair during the presentation of the question mark. In the test phase, participants had to discriminate between old, recombined, and new pairs before the end of the trial.

Due to the large amount of stimuli to be studied, the experiment was split into two study-test blocks. A schematic illustration of one study-test block can be seen in Figure 7.1. During study, word pairs of both conditions were presented intermixed. After a short delay, a definition combining the two words of a pair to a novel concept (unitization condition) or a description fitting the general meaning of the pre-existing compound pair (compound condition) was presented along with the pair. Participants were instructed to remember the pair for a subsequent memory test and to judge how well the definition or description fits to the pair treating each condition as its own reference category. Each word pair was studied twice. During test, participants were presented with old, recombined, and new pairs which they were instructed to classify as such. Familiarity is generally considered to be an automatically occurring signal (Yonelinas, 2002). Consequently, this should also hold for the postulated different kinds of familiarity signals. Thus, the two signals and the associated ERP effects should be dissociable when the two conditions are presented intermixed in the same test lists. Indeed, in the studies reported by Whittlesea and Williams (e.g., Whittlesea & Williams, 2000), expectedly fluent and unexpectedly fluent items were presented intermixed. Predominantly, the unexpectedly fluent test items were associated with a fluency-driven increase in false alarms. Therefore, conditions were likewise presented intermixed in the present experiment. At the end of the whole experimental procedure, a vocabulary test examining how well the participants remembered the meaning of the novel concepts was administered. The performance in this test provides an external measure of the goodness of conceptual integration during study.

Concerning the main aim of this experiment – to test the hypothetical link of the early parietal old/new effect and absolute familiarity and to dissociate it from the mid-frontal old/new effect – the comparison of the two types of word pairs manipulates the expectedness of conceptual fluency. Thus, I expected the early parietal old/new effect only for the unitization condition but a more frontally distributed effect in the same time window in the compound condition. In the later time window, a left parietal old/new effect was expected in both conditions as a recollection-related effect was previously reported for both conditions (Wiegand et al., 2010; Rhodes & Donaldson, 2007) when study conditions were beneficial for recollection such as studying each pair twice (Opitz, 2010a). On the behavioral level, I expected decreased memory performance for the recombined pairs in the compound compared to the unitization condition because these pairs were highly similar to the studied pairs.

The second aim of this experiment was to examine whether the early parietal old/new effect can be found outside of an explicit memory context, that is a reduced N400 for novel conceptual units in contrast to unrelated pairs. By this, a link between the N400 and the early parietal old/new effect was supposed to be established. In the current study, implicit memory conditions were created during the study phase by presenting each pair twice. At the second presentation, the novel conceptual units were already integrated and were known to the participants. However, participants were not explicitly asked if they remember the pair but had to do the same task again. Based on the reasoning described above, a reduced N400 was expected for the already integrated pairs during the second presentation in contrast to the first presentation where the pair was still completely unrelated. This effect should be greater in the unitization condition than in the compound condition as compound pairs should already be processed fluently during the first presentation. Accordingly, compound pairs should elicit a reduced N400 compared to unrelated pairs already during the first presentation as was already shown by Rhodes and Donaldson (2008a).

7.2 Methods

7.2.1 Participants

Data was collected from 20 students (10 female) from Saarland University with a mean age of 24.5 ($range: 20-31$), who were all native German speakers and right-handed as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971). Due to technical problems the EEG data of one participant was not correctly recorded in the study phase. Thus, the study phase sample was reduced to $n = 19$. The participants had no known neurological problems, normal or corrected-to-normal vision, and gave informed consent prior to taking part. They were reimbursed with course credit or 8 Euros/hour. The experiment was approved by the local ethics committee of Saarland University.

7.2.2 Stimuli

A set of 640 German nouns was used to build 80 word quadruplets in each condition which could be combined to two original word pairs and a recombined version of the pairs (see Appendix A.4 and A.5 for a full list of stimuli). Stimulus parameters are listed in Table 7.1. Mean lexical frequency (Baayen et al., 1995) did not significantly differ between the two conditions (original pairs: $t(318) = .96, p = .34$; recombined pairs: $t(158) = .1.59, p = .11$) neither did mean word pair length (original pairs: $t(318) = .80, p = .42$; recombined pairs: $t(158) = .55, p = .58$).

Word pairs in the compound condition were pre-existing German compound combinations of words. Thus, the two constituents were expected to be related and unitizable. In contrast, word pairs in the unitization condition were pre-experimentally unrelated and non-unitizable, however, were chosen to be suitable for a grammatically correct compound combination in German without requiring any further adjustments to the singular nouns. The effectiveness of this manipulation was tested in a pre-experimental rating study. All original word pairs and all recombined word pairs were rated according to relatedness and unitizability on a 4-point-scale. Each pair was rated by 10 to 13 participants (valid ratings) who did not take part in the actual experiment. Relatedness was explained in a general sense capturing categorical relatedness (feature overlap) and association (common occurrence). The scale ranged from 'not related' and 'hardly related' over 'rather related' to 'strongly related'. Unitizability denoted how suitable the pair is for forming a concept together. The scale ranged from 'not at all' and 'hardly' over 'well' to 'very well'. Mean ratings are listed in Table 7.1. As expected, compound word pairs were significantly more related (original pairs: $t(318) = 28.78, p < .001$; recombined pairs: $t(158) = 20.78, p < .001$) and more unitizable (original pairs: $t(318) = 85.12, p < .001$; recombined pairs: $t(158) = 85.85, p < .001$) than the pairs in the unitization condition.

Participants studied 120 original pairs in each condition. Compound word pairs were presented together with a definition describing the com-

Table 7.1.: Examples of word pairs used in Experiment 3 (English translations). Means (SD) are provided for lexical frequency, pair length, as well as the relatedness and unitization question in the pre-experimental rating.

	compound	**unitization**
original pairs		
example pair 1	TEE TASSE (*tea cup*)	GEMÜSE BIBEL (*vegetable bible*)
example pair 2	DESSERT LÖFFEL (*dessert spoon*)	KUSS KLAGE (*kiss complaint*)
frequency	53.03 (58.45)	60.77 (83.29)
pair length	11.04 (2.41) (range: 6 – 18)	10.85 (1.73) (range: 8 – 16)
relatedness	1.27 (.24)	2.78 (.62)
unitizability	1.26 (.22)	3.78 (.30)
recombined pairs		
example Pair	TEE LÖFFEL (*tea spoon*)	GEMÜSE KLAGE (*vegetable complaint*)
frequency	72.23 (90.74)	52.60 (63.19)
pair length	10.55 (2.52) (range: 6 – 19)	10.74 (1.70) (range: 8 – 14)
relatedness	2.62 (.54)	1.28 (.18)
unitizability	3.70 (.21)	1.34 (.13)

pound adequately (e.g., TEA CUP – *A pot which can be used to drink hot liquids*). Word pairs in the unitization condition were presented together with a definition combining the words to a novel concept (e.g., VEGETABLE BIBLE – *A book which is consulted by hobby gardeners*). Only synonyms or associates were used in the definitions in order to avoid repetitions of the words. At test, 40 pairs of the study list were repeated as old pairs and for the remaining 80 pairs the 40 recombined versions were included. Forty pairs which had not been studied served as new pairs in the test list. Assignment of pairs to old, recombined, and new pair types was counterbalanced across subjects.

7.2.3 Procedure

Before the start of the experiment, participants were fitted with an elastic cap containing the EEG electrodes. The experiment was presented using E-Prime Professional 2.0 (Psychology Software Tools, Inc.) on a 17 inch monitor. Experimental stimuli were presented in white letters in Arial font on black background. The experiment consisted of two study-test blocks. Assignment of items to blocks was counterbalanced across subjects. In study and test phases, word pairs of both pair types were presented intermixed. In each study block, a list containing 60 word pairs in each condition was presented twice (two cycles), each time in pseudo-randomized order with the constraint that no more than four items of each type were presented in a row. Participants had the general instruction to encode the word pairs for an upcoming recognition test. Moreover, for each word pair they had to decide how well the definition fitted to the concept which was denoted by the pair on a 4-point-scale ranging from '1 = fits very well' and '2 = fits well' over '3 = fits satisfactorily' to '4 = fits fairly'. Participants were pointed to the difference between the two pair types and were instructed to use the scale separately for each pair type in order to avoid that the novel units generally received bad ratings and compounds generally received good ratings. A study trial began with a 500 ms fixation cross followed by a 300 ms blank screen. Then, the pair alone was presented in 24 pt font size for 1200 ms in the center of the screen. Subsequently, the definition appeared in 17 pt font size below the pair for 3800 ms. After a 50 ms blank screen, a question mark in the middle of the screen prompted the subjects to indicate their rating by pressing the respective key. Maximal time to respond was 1500 ms. A key press, however, terminated the trial immediately and after another 50 ms blank screen, the next trial started. Participants used their index and middle fingers of both hands. The keys 'x', 'c', 'n', and 'm' corresponded to the ratings from 1–4 for every participant. After every 40 trials, there was a self-paced break.

Each of the two test blocks comprised 20 old pairs, 20 recombined pairs, and 20 new pairs. They were presented in pseudo-random order with the constraint that no more than four pairs of each condition and no more than three pairs of each pair type were presented in a row. Participants were instructed to indicate as fast and as accurately as possible if the presented pair was old, recombined, or new. A test trial started with a 800 ms fixation cross followed by a 300 ms blank screen. The pair was presented in 22 pt font size in the center of the screen lasting for 750 ms. In the following 2000 ms blank screen, participants still had the opportunity to respond. The inter-trial-interval was kept constant. Participants used their index and middle fingers of both hands to respond. The assignment of the keys 'x' and 'm' to the responses 'old' and 'new' and the use of 'c' or 'm' for the response 'recombined' was counterbalanced across subjects. After every 40 trials, there was a self-paced break. At the beginning of each study cycle and each test block, eight additional warm-up trials were included which did not enter the analyses.

After taking off the EEG cap at the end of the main experiment, participants were given a paper and pencil vocabulary test for the novel concepts. All 40 old pairs from the unitization condition were presented intermixed with 20 new pairs. For each pair, participants had to recall the definition as literally as possible or indicate that it was a new pair.

7.2.4 EEG Recording and Data Processing

EEG was continously recorded during study and test blocks with 58 Ag/AgCl electrodes which were mounted in an elastic cap according to the extended 10-20 system (Sharbrough et al., 1990). Recording was mastered with the BrainVision Recorder software (Brain Products, Inc.). Voltage differences were measured referenced to the left mastoid and re-referenced off-line to the average of the left and right mastoid. Electroocular activity was recorded with additional four electrodes, two of which were placed outside the outer canthi of both eyes and the other two above and below the right eye. The EEG was sampled with a rate of 500 Hz and was amplified with a bandpass from DC to 70 Hz and a 50 Hz notch filter. Electrode impedances were kept below 8 kΩ.

Off-line data processing was done using EEProbe software (ANT Neuro). After applying a digital bandpass filter (.02–30 Hz), 1100 ms epochs for each study and test pair were built time-locked to the onset of the stimulus and including a 100 ms pre-stimulus baseline. Prior to averaging, epochs with eye movement artefacts were corrected using a linear regression algorithm (Gratton, Coles, & Donchin, 1983) and epochs with other artefacts were rejected. Only trials attracting correct responses were averaged. This procedure resulted in a mean number (range) of averaged trials of 28.2 (20 – 38) old pairs and 26.15 (20 – 35) new pairs in the compound condition and 25.15 (13 – 34) old pairs and 23 (16 – 33) new pairs in the unitization condition. Mean voltages relative to pre-stimulus baseline in different time windows were extracted for statistical analyses. For illustration purposes a 12 Hz lowpass filter was applied to the waveforms.

7.2.5 Data Analyses

Behavioral data from the study phase consisted of the participants rating judgment. A MANOVA using Pillai's trace test statistic was conducted to compare mean ratings in the compound and unitization condition during the first and second presentation. Behavioral data from the test phase comprised accuracy (percentage of correct responses) and reaction times for each condition and pair type. Inferential statistics included MANOVAs with the factors of Condition (compound, unitization) and Pair Type (old, recombined, new).

ERP inferential statistics were conducted on mean amplitudes in time windows according to the predicted effects and visual inspection of the waveforms. ERPs in the study phase were analyzed between 380 and 580 ms after stimulus onset for the N400 time window. An additional time window from 600 to 800 ms was analyzed to examine the later effects covering effects more related to the second word of the pair. The overall MANOVA in each time window included the within-subjects factors of Condition (compound, unitization), Presentation (first, second), Anterior-Posterior (frontal, central, parietal), and Laterality (left, midline, right). Only effects involving the factors Condition and Presentation are reported as those are the the effects in the focus of interest. Non-significant effects are generally not reported for reasons of clarity. ERPs in the test phase were analyzed in a 360 to 540 ms time window to cover the early old/new effects. The second window covering the left parietal old/new effect started at 590 ms and ended at 750 ms, which was isochronic with the offset of the word pair. The overall MANOVA in each time window included the within-subjects factors of Condition (compound, unitization), Pair Type (old, new), Anterior-Posterior (frontal, central, parietal), and Laterality (left, midline, right). Recombined pairs were not analyzed as they were not in the focus of interest and they are hard to interpret as they might contain conflicting signals (the constituents are old, but the pair is new) which are difficult to tear apart in such a spatially integrating measure as ERPs.

The significance level was set to $\alpha = .05$. In post-hoc pair-wise comparisons, p-values are marked as non-significant (ns.) when they failed to reach significance after adjustment using the Bonferroni-Holm procedure (Holm, 1979).

7.3 Results

7.3.1 Behavioral Results

Study Phase

During the first presentation, participants' mean rating was $M = 1.61$ ($SE = .06$) in the compound condition and $M = 2.82$ ($SE = .10$) in the unitization condition. During the second presentation, the mean rating was $M = 1.66$ ($SE = .07$) in the compound condition and $M = 2.90$ ($SE = .10$) in the unitization condition. MANOVA over all pairs with the within-subject factors Condition (compound, unitization) and Presentation (first, second) yielded a significant main effect of Condition ($F(1, 18) = 80.95, p < .001$), a significant main effect of Presentation ($F(1, 18) = 6.802, p < .001$), but no significant interaction ($F < 1$). Ratings during first and second presentation were highly consistent as revealed by an item-based ($n = 180$) Pearson's correlation coefficient of $r = .92$ ($p < .001$) in the compound condition and $r = .86$ ($p < .001$) in the unitization condition. Using Fisher's r-to-z-transformation it was revealed that the correlation coefficient in the compound condition was significantly larger than in the unitization condition ($Z = 2.86, p < .01$). Thus, the fit of the pair and the description was generally perceived as better in the compound condition. Moreover, participants generally applied a stricter criterion during the second presentation. There was a strong consistency in the ratings from first to second presentation which was even stronger in the compound condition.

Test Phase

As can be seen in Figure 7.2.A, old and new pairs were better recognized in the compound than in the unitization condition but recombined pairs were better recognized in the unitization condition. A MANOVA on accuracy revealed a main effect of Pair Type ($F(2, 18) = 30.42, p < .001$) and an interaction of Pair Type by Condition ($F(2, 18) = 46.98, p < .001$) but no main effect of Condition ($F < 1$). Deconstruction of the interaction by pair-wise comparisons showed that in the compound condition old pairs ($M = .91, SE = .02$) were better recognized than recombined pairs ($M = .50, SE = .03$, $t(19) = 10.55, p < .001$) and new pairs ($M = .86, SE = .02$) were better recognized than recombined pairs ($t(19) = 8.88, p < .001$). Moreover, the difference between old and new pairs failed to reach significance ($t(19) = 2.60, p = .018, ns.$). In contrast, in the unitization condition old pairs ($M = .82, SE = .03$), recombined pairs ($M = .74, SE = .03$), and new pairs ($M = .74, SE = .03$) were recognized on a comparable level. All t-tests were not significant (old vs. recombined: $t(19) = 2.16, p = .04, ns.$; old vs. new: $t(19) = 1.98, p = .06$, $ns.$; recombined vs. new: $t(19) < 1$). Comparisons between compound and unitization condition revealed that compounds were better recognized when the pair type was old ($t(19) = 3.66, p < .01$) and when it was new ($t(19) = 6.00, p < .001$). However, performance was better in the unitization condition than the compound condition for recombined pairs ($t(19) = 8.18, p < .001$).

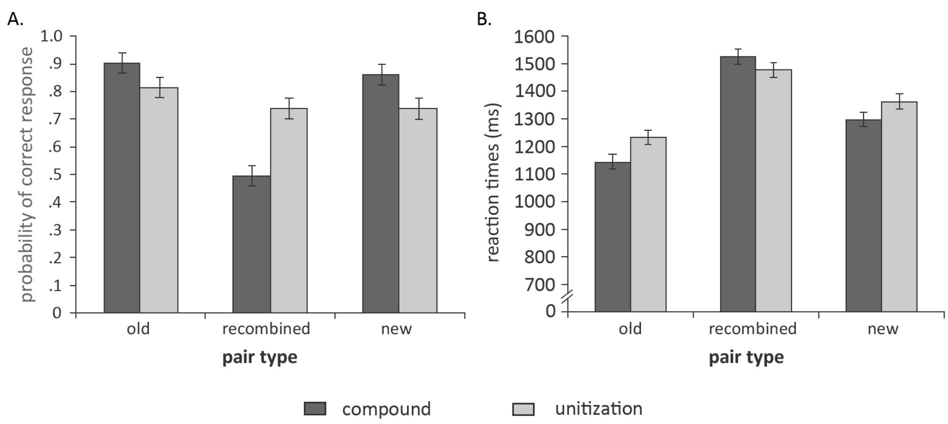


Figure 7.2.: Mean probabilities of correct responses (A.) and mean reaction times (B.) for old, recombined, and new pairs in the compound and unitization condition in Experiment 3. Error bars indicate 95% confidence intervals for the interaction term (Jarmasz & Hollands, 2009).

Table 7.2.: Mean proportion of incorrect responses for all three pair types in the two conditions. rec = recombined.

	old pairs		**rec pairs**		**new pairs**	
	'rec'	'new'	'old'	'new'	'old'	'rec'
compound	.06 (.01)	.03 (.01)	.22 (.02)	.27 (.02)	.01 (.01)	.12 (.02)
unitization	.15 (.02)	.04 (.01)	.08 (.01)	.16 (.02)	.02 (.01)	.23 (.03)

Table 7.2 shows mean proportions of incorrect responses. As can be seen, old pairs rarely attracted incorrect responses, but if any it were 'recombined' responses. Recombined pairs were more likely classified as 'new' than 'old' mirroring the pattern for new pairs which were more likely classified as 'recombined' than 'old'. Incorrect responses were analyzed in three separate Condition by Response MANOVAs. For old pairs, the MANOVA revealed significant main effects of Condition ($F(1, 19) = 32.43, p < .001$) and Response ($F(1, 19) = 15.02, p < .001$) as well as a significant interaction ($F(1, 19) = 13.65, p < .01$). Follow-up t-tests revealed that incorrect 'recombined' responses were more frequent in the unitization condition than in the compound condition ($t(19) = 4.04, p < .01$), but there was no difference between conditions for 'new' responses ($t(19) = 1.10, p = .29$). For recombined pairs, the MANOVA revealed only significant main effects of Condition ($F(1, 19) = 87.16, p < .001$) and Response ($F(1, 19) = 7.63, p < .05$) indicating more incorrect responses in the compound condition and more incorrect 'new' responses than 'old' responses. For new pairs, significant main effects of Response ($F(1, 19) = 36.05, p < .001$) and Condition ($F(1, 19) = 33.55, p < .001$) and a significant interaction ($F(1, 19) = 14.75, p < .01$) were yielded. Follow-up t-tests could show that the interaction indicated that there was no significant difference between conditions for 'old' responses ($t(19) = 1.10, p = .29$), but for 'recombined' responses ($t(19) = 5.10, p < .001$).

Reaction times show the mirror pattern of the accuracy data (see Figure 7.2.B). For old and new pairs, reaction times were faster for compounds than for novel units but for recombined pairs they were faster for novel units than for compounds. A MANOVA on reaction times revealed significant main effects of Condition ($F(2, 18) = 14.56, p < .01$) and Pair Type ($F(2, 18) = 52.43, p < .001$) as well as a significant interaction ($F(2, 18) = 10.53, p < .01$). Post-hoc comparisons for the compound condition showed that old pairs ($M = 1145, SE = 32$) were recognized faster than recombined pairs ($M = 1526, SE = 49, t(19) = 12.16, p < .001$) and than new pairs ($M = 1298, SE = 52, t(19) = 5.10, p < .001$). Moreover, new pairs were recognized faster than recombined pairs ($t(19) = 5.47, p < .001$). Similarly, in the unitization condition reaction times for old pairs ($M = 1235, SE = 32$) were faster than for recombined pairs ($M = 1479, SE = 50, t(19) = 6.74, p < .001$) and than for new pairs ($M = 1363, SE = 51, t(19) = 4.05, p < .01$). Reaction times for new pairs were faster than for recombined pairs ($t(19) = 3.19, p < .01$). Comparisons between conditions showed significantly faster reaction times for the compound than the unitization condition for old pairs ($t(19) = 5.46, p < .001$) and new pairs ($t(19) = 3.95, p < .01$) whereas the reversed pattern was shown for recombined pairs ($t(19) = 2.56, p < .05$). Analyses of the behavioral data revealed that performance for old and new pairs was better and faster in the compound than in the unitization condition. This performance decrease in the unitization condition can mainly be attributed to an increased misclassification of old and new pairs as 'recombined'. However, the pattern was flipped for recombined pairs for which there was a decrease in accuracy in the compound condition which resulted in slightly but not significantly worse associative memory than in the unitization condition. This selective decrease could not be traced back to a specific type of incorrect response.

7.3.2 ERP Results

Study Phase

Figure 7.3 shows grand average ERPs elicited by the pairs in both conditions during first and second presentation. ERPs to compound pairs during the second presentation start to diverge in the positive direction from the other ERPs in the N400 time window at around 400 ms after stimulus onset at left and midline electrode sites. From about 600 to 800 ms, ERPs to compounds are generally more positive than those to the pairs in the unitization condition. Moreover, ERPs during the second presentation are generally more positive than first presentation ERPs. These late effects are most pronounced at centro-parietal scalp sites.

Early Time Window: 380 – 580 ms The overall MANOVA on mean amplitudes with the within-subjects factors Condition (Compound, Unitization), Presentation (first, second), Anterior-Posterior (frontal, central, parietal), and Laterality (left, midline, right) for the early time

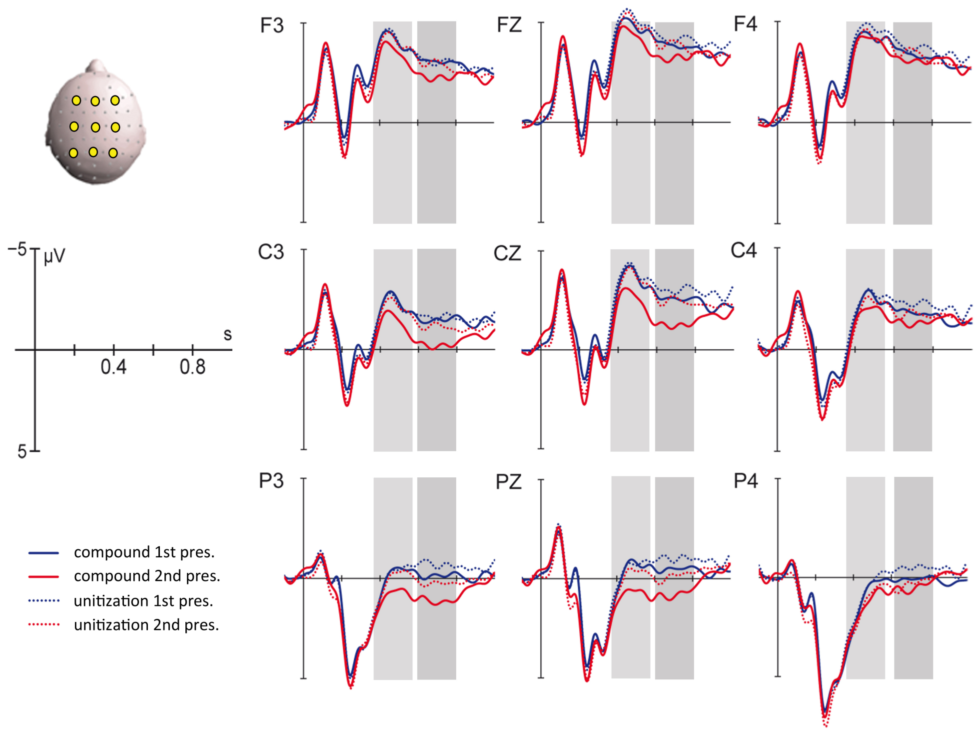


Figure 7.3.: Grand average ERPs elicited by pairs in the compound and unitization condition presented during the first and second presentation in the study phase. Data are shown for the nine electrode sites entering the analyses at frontal (F3, Fz, F4), central (C3, Cz, C4), and parietal (P3, Pz, P4) locations as indicated on the scalp layout. Time windows selected for analyses are shaded in light (early) and darker grey (late).

window revealed a significant main effect of Presentation ($F(1, 18) = 4.53, p < .05$), significant interactions of Condition × Laterality ($F(2, 17) = 6.96, p < .01$) and Condition × Presentation × Laterality ($F(2, 17) = 6.86, p < .01$), as well as a marginally significant interaction of Presentation × Laterality ($F(2, 17) = 3.01, p < .08$). Deconstructing the three-way interaction, separate MANOVAs were conducted for all three levels of Laterality. On the left hemisphere, this analysis yielded a marginally significant main effect of Presentation ($F(1, 18) = 3.69, p < .08$) and a significant interaction of Condition × Presentation ($F(1, 18) = 6.58, p < .05$). At midline electrodes, it revealed a significant main effect of Presentation ($F(1, 18) = 5.14, p < .05$) and a marginally significant main effect of Condition ($F(1, 18) = 3.29, p < .09$) as well as a marginally significant interaction of Condition × Presentation ($F(1, 18) = 3.09, p < .1$). On the right hemisphere, the MANOVA revealed only a marginally significant main effect of Presentation ($F(1, 18) = 4.12, p < .06$). To follow-up the significant interaction of Condition × Presentation on the left

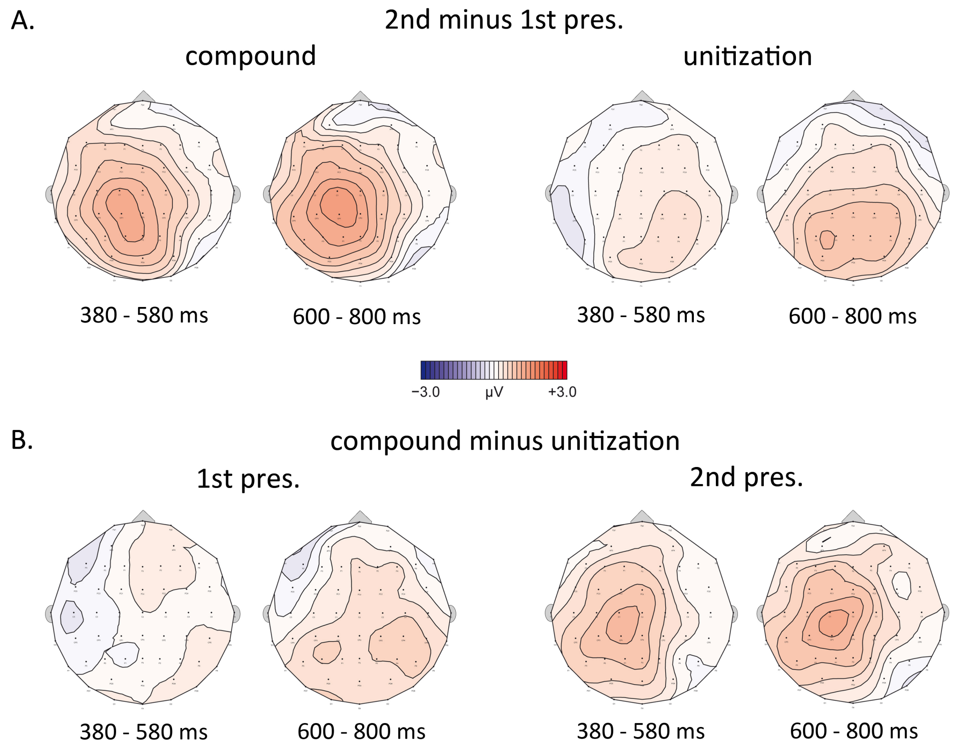


Figure 7.4.: Topographic maps showing the topographical distribution of the critical differences in the study phase in the early and late time window. A. Difference waves were obtained by subtracting ERPs associated with the first presentation from those associated with the second presentation for the compound (left) and unitization (right) condition. B. Difference waves were obtained by subtracting ERPs associated with the unitization condition from those with the compound condition for the first (left) and second (right) presentation.

hemisphere, separate MANOVAs for first and second presentation were conducted. For the first presentation there were no significant effects whereas for the second presentation a significant main effect of Condition was found ($F(1, 18) = 7.40, p < .05$).

The main result of the analyses of the early time window is a Condition effect which is moderated by Presentation. Thus, a reduced N400 amplitude for the compound in contrast to the unrelated pairs in the unitization condition was only found during the second presentation. Moreover, a reduction from first to second presentation was only found in the compound condition but not in the unitization condition. This pattern of results was most pronounced at left electrode sites whereas at right electrode sites the effects are smaller. Topographic distributions over the scalp of the reported effects can be seen in Figure 7.4.

Late Time Window: 600 – 800 ms In the late time window, a MANOVA on mean amplitudes with the within-subjects factors Condition (Compound, Unitization), Presentation (first, second), Anterior-Posterior (frontal, central, parietal), and Laterality (left, midline, right) yielded a significant main effect of Presentation ($F(1, 18) = 5.95, p < .05$), a marginally significant effect of Condition ($F(1, 18) = 3.39, p < .09$), significant interactions of Condition × Laterality ($F(2, 17) = 5.03$, $p < .05$), Condition × Presentation × Laterality ($F(2, 17) = 4.10, p < .05$), and Condition × Anterior-Posterior × Laterality ($F(4, 15) = 4.03$, $p < .05$), as well as a marginally significant interaction of Presentation × Laterality ($F(1, 18) = 7.401, p < .05$). Subsequently, separate MANOVAs for all levels of Laterality were conducted to dissolve the three-way interactions. At left-hemispheric electrodes, a main effect of Presentation ($F(1, 18) = 7.58, p < .05$) and a marginally significant main effect of Condition ($F(1, 18) = 3.27, p < .09$) were revealed. On the midline, the MANOVA showed significant main effects of Condition ($F(1, 18) = 4.45, p < .05$) and Presentation ($F(1, 18) = 5.84, p < .05$) as well as a significant interaction of Condition × Anterior-Posterior ($F(2, 17) = 4.97, p < .05$). On the right hemisphere, this analysis yielded only a marginally significant main effect of Presentation ($F(1, 18) = 3.31, p < .09$). In order to deconstruct the Condition × Anterior-Posterior interaction at midline electrodes, three further analyses were conducted at each level of Anterior-Posterior. No significant effects were found at electrode Fz. At electrode Cz, main effects of Condition ($F(1, 18) = 5.41, p < .05$) and Presentation ($F(1, 18) = 5.86, p < .05$) were revealed. The MANOVA at Pz yielded main effects of Condition ($F(1, 18) = 5.36, p < .05$) and Presentation ($F(1, 18) = 7.22, p < .05$), too.

The main finding in the late time window were two independent effects of Condition and Presentation which were most pronounced at centro-parietal midline electrodes. In a last set of analyses for this time window, I wanted to test the reliability of the Condition effect for each presentation separately and likewise the reliability of the Presentation effect for each condition at the two electrodes where the effects were most pronounced. Pair-wise t-tests revealed that the two conditions did not significantly differ during the first presentation (Cz: $t(18) = 1.34, p = .20$; Pz: $t(18) = 1.42, p = .17$), but only during the second presentation (Cz: $t(18) = 2.77, p < .05$; Pz: $t(18) = 2.49, p < .05$). Moreover, an amplitude reduction from first to second presentation was found for the compound condition at both electrode sites (Cz: $t(18) = 2.54, p < .05$; Pz: $t(18) = 2.26, p < .05$) whereas in the unitization condition only at electrode Pz (Cz: $t(18) = 1.64, p = .12$; Pz: $t(18) = 2.75, p < .05$). Hence, although there was no interaction of Condition and Presentation, a robust effect of Condition can only be found during the second presentation. However, the effect of Presentation can be observed for both conditions although it is topographically more restricted in the unitization condition.

Test Phase

As depicted in Figure 7.5, ERPs from the compound and unitization conditions start diverging at around 300 ms after stimulus onset predominantly at frontal electrode sites with compound pairs eliciting more positive-going waveforms. This difference extends over the whole scalp from about 380 ms on until about the end of the recording epoch. Old and new test pairs in the compound condition minimally differ already from 300 ms at frontal sites. However, considerable old/new effects in both conditions can only be observed from 600 ms after stimulus onset on.

Early Time Window: 360 – 540 ms A MANOVA with the factors Condition (compound, unitization), Pair Type (old, new), Anterior-Posterior (frontal, central, parietal), and Laterality (left, midline, right) in the early time window revealed a significant main effect of Condition ($F(1, 19) = 5.69, p < .05$) and a significant interaction of Condition × Laterality ($F(2, 18) = 6.61, p < .01$). In order to dissolve the interaction, separate analyses were conducted for all levels of laterality. At left and midline electrode sites, a significant main effect of Condition was yielded ($left$: $F(1, 19) = 8.31, p < .05$; *midline*: $F(1, 19) = 7.54, p < .05$). There were no significant effects over the right hemisphere.

Addressing my specific hypotheses regarding the presence and topographical distribution of the early effects in the two conditions, I conducted separate MANOVAs for each condition at frontal and parietal electrode sites with the factors of Pair Type (old, new) and Laterality (left, midline, right). In the compound condition, the MANOVA at frontal sites revealed a marginally significant interaction of Pair Type × Laterality ($F(2, 18) = 3.29, p < .07$). No effects were found at parietal sites. The follow-up t-tests at the frontal electrodes, however, could not

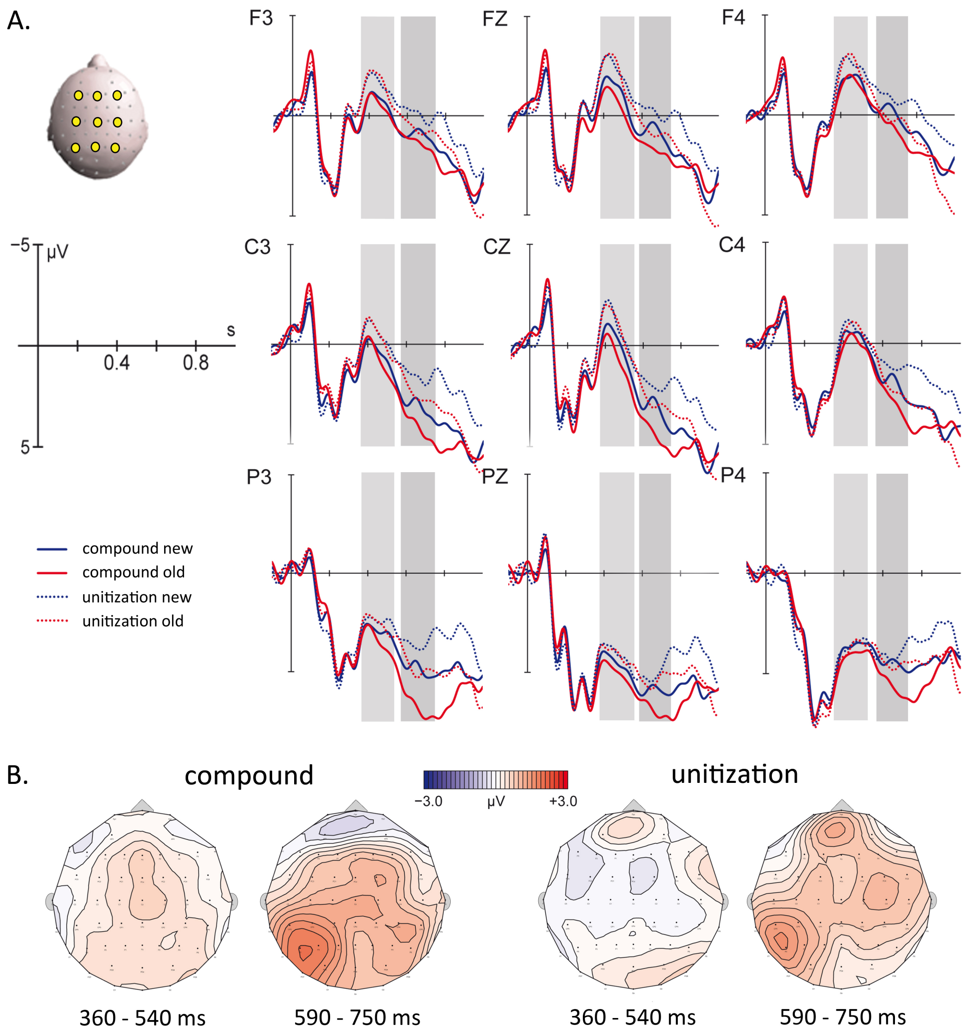


Figure 7.5.: A. Grand average ERPs elicited by old and new pairs in the compound and unitization condition in the test phase. Data are shown for the nine electrode sites entering the analyses at frontal (F3, Fz, F4), central (C3, Cz, C4), and parietal (P3, Pz, P4) locations as indicated on the scalp layout. Time windows selected for analyses are shaded in light (early) and darker grey (late). B. Topographic maps showing the topographical distribution of the critical differences in the test phase in the early and late time window for the compound (left) and unitization (right) condition. Difference waves were obtained by substracting ERPs associated with new pairs from those with old pairs.

detect any significant old/new effects ($F3$: $t(19) = 1.24, p = .23$; Fz: $t(19) = 1.39, p = .18$, $F4$: $t < 1$). In the compound condition, there were no significant effects at both scalp locations (F-*values* < 1).

Analyses of the ERPs in the early time window showed that early old/new effects could not be detected in either condition. Only the effect of generally more positive ERPs for the compound condition in contrast to the unitization condition over the left hemisphere was replicated from the study phase.

Late Time Window: 590 – 750 ms In the late time window, a MANOVA with the factors Condition (compound, unitization), Pair Type (old, new), Anterior-Posterior (frontal, central, parietal), and Laterality (left, midline, right) revealed significant main effects of Condition ($F(1, 19) = 14.35, p < .01$) and Pair Type ($F(1, 19) = 5.65, p < .05$) as well as a significant interaction of Pair Type $\times$ Anterior-Posterior $\times$ Laterality ($F(4, 16) = 7.74, p < .01$). Moreover, it showed marginally significant interactions of Condition $\times$ Laterality ($F(2, 18) = 3.42, p < .06$) and Condition $\times$ Anterior-Posterior $\times$ Laterality ($F(4, 16) = 2.78, p < .07$). Deconstructing the three-way interactions involving the factor Laterality, separate analyses were conducted on each level of this factor. On the left hemisphere, a MANOVA revealed a reliable main effect of Condition ($F(1, 19) = 22.03, p < .001$) and a reliable main effect of Pair Type ($F(1, 19) = 6.77, p < .05$) as well as a significant interaction of Pair Type $\times$ Anterior-Posterior ($F(2, 18) = 4.61, p < .05$) and a marginally significant interaction of Condition $\times$ Anterior-Posterior ($F(2, 18) = 2.67, p < .1$). Over the midline, the analysis revealed significant main effects of Condition ($F(1, 19) = 11.69, p < .01$) and Pair Type ($F(1, 19) = 4.47, p < .05$). Similarly on the right hemisphere, significant main effects of Condition ($F(1, 19) = 5.77, p < .05$) and Pair Type ($F(1, 19) = 4.70, p < .05$) were revealed. Following-up the two-way interactions involving the factor Anterior-Posterior at left recording sites, separate MANOVAs revealed a significant effect of Condition at all three electrodes (F3: $F(1, 19) = 5.84, p < .05$, C3: $F(1, 19) = 20.14, p < .001$; P3: $F(1, 19) = 13.70, p < .01$). Significant main effects of Pair Type were revealed only at C3 ($F(1, 19) = 4.91, p < .05$) and P3 ($F(1, 19) = 10.84, p < .01$), but not F3 ($F(1, 19) = 2.08, p = .17$).

In order to check if the old/new effects can be found independently in each condition, post-hoc t-tests checked the reliability of the old/new effects for each condition separately at electrodes C3 and P3 where the effects were maximal. At electrode C3, there was only a marginally significant effect in the compound condition ($t(19) = 2.11, p < .05, p < .1$ after correction) , but not in the unitization condition ($t(19) = 1.41, p = .17$). At P3, the t-test revealed a significant difference in the compound condition ($t(19) = 3.05, p < .01$) and a marginally reliable effect in the unitization condition ($t(19) = 2.06, p = .053$). In sum, a left parietal old/new effect was present in both conditions albeit with a smaller spatial extent in the unitization condition.

7.3.3 Analysis According to Study Phase Rating

Wiegand et al. (2010) showed that for same old pairs at test the goodness of conceptual integration influenced recognition speed and the early parietal old/new effect. More specifically, well integrated pairs (plausible study phase rating of '1' or '2') were recognized faster than poorly integrated pairs (implausible study phase rating of '3' or '4') and the early old/new effect could only be observed for the former but not the latter. No such influence was found on the early mid-frontal old/new effect for the reversed pairs. Following this rationale, the subsequent set of analyses aimed to investigate whether the study phase rating correlated with test performance and whether the early old/new effect can be observed for plausible old pairs.

For this purpose, the trials were split into plausible (rating '1' or '2') and implausible ('3' or '4') pairs taking the ratings given during the second presentation as a basis. The procedure of splitting the pairs resulted generally in very few or zero trials in some of the conditions for some of the participants. Due to this and equipment failure the remaining sample for the behavioral data of the test phase was $n = 16$. Reaction times were expected to be faster for plausible than for poorly integrated pairs. For the ERP analyses the lower bound for the number of averaged trials was set to 8. In order to keep as many subjects as possible in the analyses, only the plausible pairs were used. The remaining sample size was nonetheless reduced further to $n = 11$. The mean number of averaged trials was 23.73 (14 – 38) in the compound condition and 11.91 (8 – 19) in the unitization condition. The analyses focused on the early time window as the hypotheses targeted the early parietal old/new effect. I expected an early parietal old/new effect to be present when using only the plausible pairs in the unitization condition, but no such influence on the early (frontal) effect in the compound condition. The small trial number and small sample sizes imply that caution is warranted for any conclusions that might potentially be drawn from these ERP analyses.

Behavioral Data

Mean proportion correct and reaction times are listed in Table 7.3 showing a small performance advantage and a speed-up for plausible in con-

Table 7.3.: Mean proportion of correct responses and mean reaction times according to study phase rating for plausible (study phase rating of '1' and '2') and implausible pairs (study phase rating of '3' and '4') in the compound and unitization condition. Standard errors are given in parentheses. Note the smaller sample size of $n = 16$.

	proportion correct		**reaction times (ms)**	
	plausible	implausible	plausible	implausible
compound	.88 (.02)	.82 (.04)	1144 (38)	1184 (48)
unitization	.84 (.05)	.80 (.04)	1221 (43)	1254 (37)

trast to implausible pairs in both conditions. A MANOVA with the factors Condition (compound, unitization) and Plausibility (plausible, implausible) on the accuracy data revealed neither a main effect of Condition ($F(1,15) = 1.62, p = .22$) nor a main effect of Plausibility and no interaction (*F-values* < 1). However, a MANOVA on the reaction times revealed a significant effect of Condition ($F(1,15) = 12.26, p < .01$) and a significant effect of Plausibility ($F(1,15) = 6.10, p < .05$), but no significant interaction ($F < 1$). Thus, a reliable advantage resulting from a good integration during study was only observable in response speed.

ERPs

Figure 7.6 depicts grand average waveforms for ERPs to all old pairs and only plausible pairs as well as new pairs. It can be seen that in the compound condition, the plausible pairs virtually do not differ from all old pairs. In the unitization condition, however, it seems that at parietal electrodes the pairs elicit a more positive-going waveform than all old pairs. Report of the statistical analyses is restricted to the unitization condition as the hypotheses were targeted to this condition. Neither the overall MANOVA with the factors Pair Type (old, new), Anterior-Posterior (frontal, central, parietal), and Laterality (left, midline, right) revealed any significant effects involving the factor Pair Type (*F-values* < 1.2) nor did targeted t-tests at electrodes Cz and Pz reveal a significant difference between old and new pairs (Cz: $t < 1$; Pz: $t(10) = 1.42, p = .19$). Thus, an early parietal old/new effect could not be observed for only plausible old pairs either.

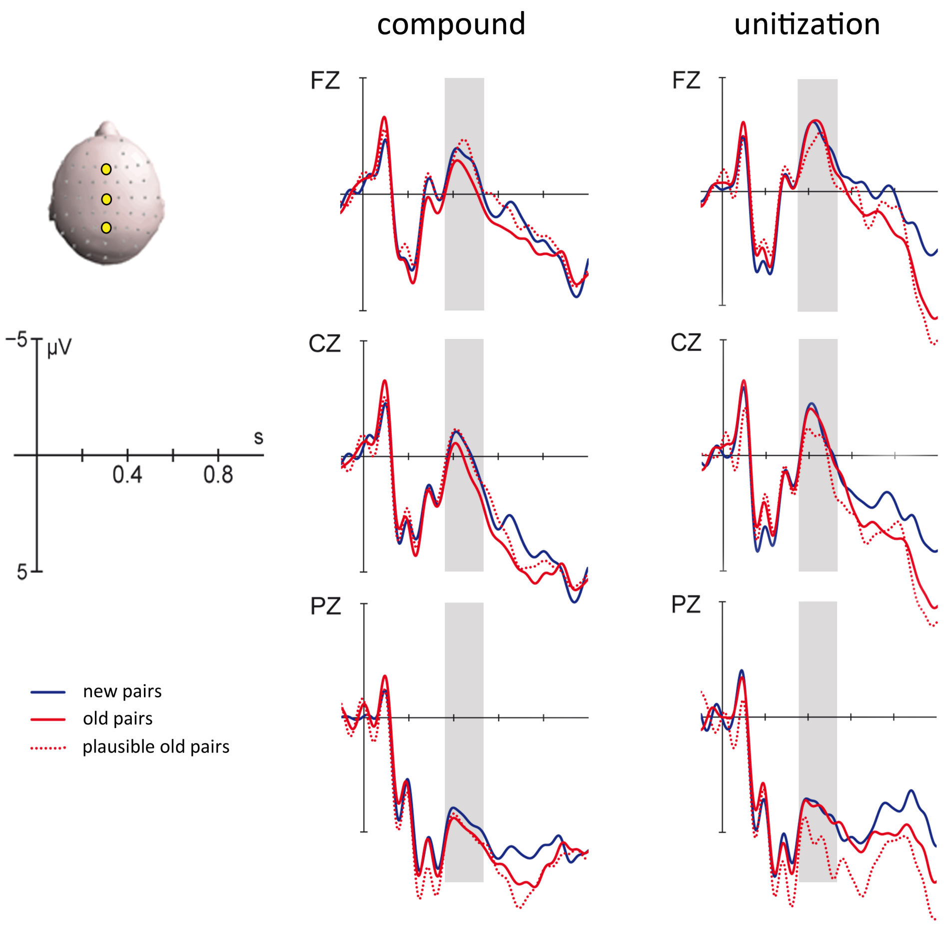


Figure 7.6.: Grand average ERPs elicited by old, new, and plausible old pairs in the compound and unitization condition in the test phase. Data are shown for three midline electrode sites (Fz, Cz, Pz) as indicated on the scalp layout. The time window selected for analyses is shaded in light grey. Note the smaller sample size of $n = 11$.

7.3.4 Vocabulary Test

The vocabulary test was administered to the participants as it provides an external measure of the goodness of conceptual integration during the study phase. Since the early parietal old/new effect at test is thought to reflect the ease of conceptual processing which in turn should be fostered by a strong conceptual integration, I expected the effect to be present for old pairs for which the meaning could be recalled. Before I turn to the ERP analyses, the performance in the vocabulary test will be reported.

Vocabulary Test Performance

Subjects' responses in the vocabulary test were classified in four categories. If the response was missing or was completely wrong, the response was coded as '0'. If the principal meaning was correct, but parts were reproduced incorrectly or were missing, the response was coded as '1'. If the principal meaning was reported completely, the response was coded as '2'. Finally, if the definition was recalled literally, the response was coded as '3'.

On average, participants scored 8.4 times '0', 8.6 times '1', 22.0 times '2', and 1.05 times '3'. Thus, although the literal definition could only rarely be reproduced, participants could remember the general meaning of the 40 studied pairs.

Relationship of Behavioral Performance and Vocabulary Test Outcome

The outcome of the vocabulary test was further analyzed on the item level in order to relate memory for the meaning to performance in the recognition test. Table 7.4 lists the classification of all items (40 studied items $\times$ 20 subjects) according to whether they were correctly or incorrectly remembered in the recognition test. As can be seen, there was a relationship between the score yielded in the vocabulary test and recognition memory performance. The better the score in the vocabulary test, the more likely was a correct response in the recognition test. Statistical analysis of this contingency yielded a significant Kendall's tau-b value of $= .22$ ($p < .001$). Moreover, a correlation analysis restricted to the correct items ($n = 623$) from the recognition test revealed a negative relationship of vocabulary score and reaction times in the recognition test (Kendall's tau-b$= -.09, p < .01$). The reported set of analyses implies that meaning acquisition of the novel concepts goes along with better and faster performance in the recognition memory test.

Table 7.4.: Classification in the vocabulary test according to accuracy during the recognition test. Vocabulary test classification: 0 = missing or incorrect; 1 = principal meaning correct, but parts missing or incorrect; 2 = complete report of principal meaning; 3 = literal reproduction of the definition.

	vocabulary test score				
	0	1	2	3	total
correct	95	138	370	20	623
incorrect	72	34	70	1	177
total	167	172	440	21	800*

*corresponds to 40 studied items $\times$ 20 subjects

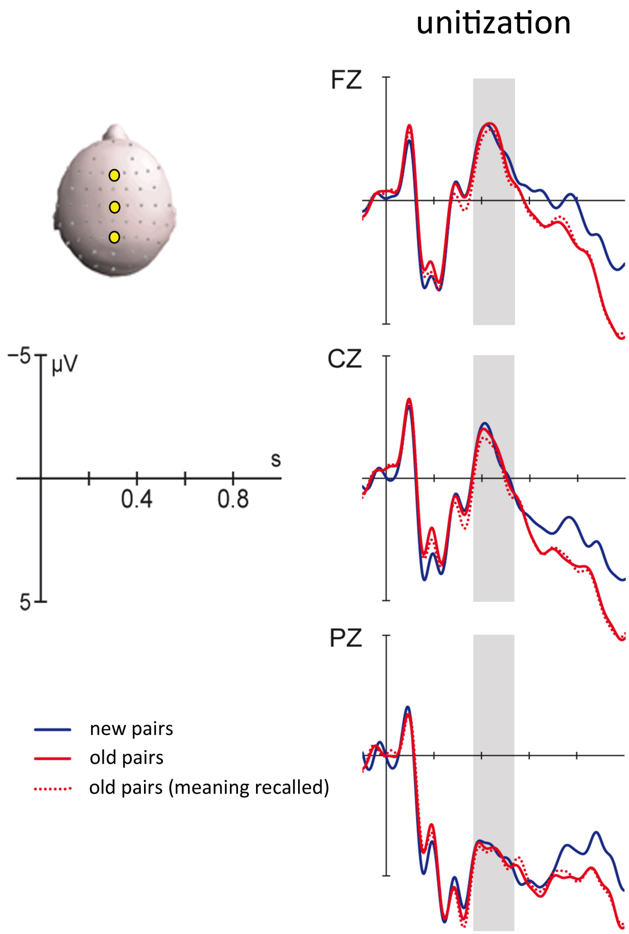


Figure 7.7.: Grand average ERPs elicited by old, new, and those old pairs for which the general meaning could be recalled in the unitization condition in the test phase. Data are shown for three midline electrode sites (Fz, Cz, Pz) as indicated on the scalp layout. The time window selected for analyses is shaded in light grey.

ERPs to Old Pairs for Which Meaning Could be Recalled

As described above, the outcome of the vocabulary test was expected to explain variance also in the ERP analyses. Thus, the ERP analyses in this section focuses on those pairs for which the general meaning of the novel concept could be correctly recalled (i.e., vocabulary score 1 – 3).

Grand average ERPs for all old pairs and for those old pairs for which the meaning was recalled as well as new pairs are shown in Figure 7.7. It is clear from the figure that also for the restricted set of items an early old/new effect cannot be observed. A MANOVA with the factors Pair Type (old-meaning recalled, new), Anterior-Posterior (frontal, central, parietal), and Laterality (left, midline, right) confirmed that there were no significant effects involving the factor Pair Type (F-$values < 1$). Moreover, targeted t-tests could not reveal significant differences at electrode Cz or Pz (t-$values < 1$). Hence, meaning acquisition did not have a nameable influence on the early parietal old/new effect.

7.4 Discussion

Experiment 3 compared ERP old/new effects during study and retrieval of word pairs from two different conditions. Word pairs in the compound condition were pre-existing compound word pairs associated with a single concept. In contrast, word pairs in the unitization condition were pre-experimentally unrelated, but were presented together with a definition which was intended to combine the two words to a novel concept. Both types of pairs are assumed to form a unitized representation. However, in the compound condition, participants could rely on pre-existing links in their semantic memory. In contrast, unitization in the unitization condition took place only during the experiment. Thus, a new link had to be formed. The aim of Experiment 3 was to directly contrast the two types of pairs which differ only in the expectedness of fluent conceptual processing and the novelty of the representation. It was expected that pairs in the compound and unitization condition automatically elicit the early mid-frontal and the early parietal old/new effect, respectively. A second aim of the study was to investigate the early parietal old/new effect under implicit memory conditions during the study phase of the experiment.

7.4.1 Behavioral Data

Although the participants were instructed to apply different scales for the study phase rating for the two conditions, they generally rated the fit of the description and the word pair better in the compound condition than in the unitization condition. This is plausible as the description generally matched the known meaning of the compound. Moreover, participants seem to have applied a stricter criterion during the second than during the first presentation. However, more importantly, the ratings during the first and second presentation showed a high correspondence indicating a high reliability of the subjects' ratings. The finding that the correlation was a bit higher in the compound than the unitization condition is likely due to the possibility to evaluate the description against an established meaning, a possibility which is missing in the unitization condition where the rating is more subjective. This makes it even more remarkable that the correlation in the unitization condition is still very high suggesting that the participants have quite a strong feeling what a specific combination of words should mean. Thus, the analysis of the rating data suggests that the unitization instruction employed in this experiment seems to be suitable and the ratings can further be used as a reliable indicator of how well the description fitted the pair.

Analysis of performance in the recognition test revealed that old and new pairs were better recognized in the compound than in the unitization condition. In contrast, the reversed pattern was found for recombined pairs. A closer look at the incorrect responses revealed that old and new pairs in the unitization condition were less likely misclassified as 'new' or 'old' than in the compound condition. Thus, although the proportion of hits and correct rejections was lower than in the compound condition, old/new discrimination was on a high level. This probably comes about the circumstance that old and new pairs are highly discriminable due to the presence and absence of meaning. This supposition is fostered by the inclusion of the vocabulary test outcome into the analysis which showed that the likelihood of correct recognition of an old pair rises with increasing completeness of the definition recalled. The lack of this source of discrimination in the compound condition is visible in the finding that recombined pairs were recognized on a relatively low level. For these pairs, feature overlap between recombined and studied pairs is very high (e.g., *dessert spoon* vs. *tea spoon*) which makes them hard to distinguish. Moreover, the descriptions which were used for highly similar concepts are likewise highly similar. Thus, recollection of the description offers only poor evidence for a correct decision.

Mirroring the accuracy data, old and new pairs were recognized faster in the compound condition whereas recombined pairs were recognized faster in the unitization condition. Thus, word pairs which are connected with a pre-existing representation in semantic memory seem to be accessible much faster than just established concepts. Only when the highly similar foils have to be rejected, responses become slower. In both conditions, reaction times for old pairs were faster than for new pairs. For newly unitized pairs it has previously been suggested that this reflects increased conceptual fluency during test (Bader et al., 2010; Wiegand et al., 2010, see also Experiment 1). The current finding is not at odds with this notion. Conceptual fluency should also be increased by a single presentation of a pre-existing compound pair. Consistent with this interpretation are also the findings that pairs with good ratings during study were recognized faster than those with poor ratings. Moreover, the more details were remembered for a specific pair in the vocabulary test, the faster were the reaction times. Thus, a better integration into semantic memory leads to better accessibility. However, an alternative explanation could be that better memory for the meaning goes along with stronger and also faster recollection.

7.4.2 Study Phase ERPs

Investigation of the ERPs in the N400 time window during the study phase revealed no difference between compound and unitization condition during the first presentation. Only during the second presentation, a difference between the conditions was found with compound pairs eliciting more positive going waveforms. Moreover, compound pairs elicited more positive going waveforms during the second than during the first presentation. This pattern and the centro-parietal scalp distribution suggests that the differences reflect an N400 effect. Word pairs in the unitization condition were not reduced from first to second presentation. The pattern in the early time window, however, cannot be evaluated without taking into account subsequent processing reflected in ERPs in the late time window. Here, a robust difference between the conditions can also only be found during the second presentation. However, in contrast to the first time window, an amplitude reduction from first to second presentation was not only found in the compound condition but also in the unitization condition. Although the later time window does not correspond with the N400 time window, it is conceivable that the effects in this time window could reflect processes normally associated with the N400. The topographical distributions of the later effects are highly similar to what was observed in the early time window. Thus, a successful unitization process is probably reflected in the reduced amplitudes during the late time window.

These results differ in two aspects from the expectations. First, already during the first presentation compound word pairs were expected to elicit more positive going ERPs than the (at this time point) completely unrelated word pairs in the unitization condition. The current finding is also not consistent with the report of Rhodes and Donaldson (2008a) who found that association word pairs (compound pairs and non-compound pairs) were associated with a reduced N400 compared to semantically related and unrelated word pairs. An explanation for this divergence might come from the kinds of stimuli employed. Rhodes and Donaldson used opaque compound stimuli as association word pairs. The meaning of opaque compounds cannot be derived from the meaning of their constituents (e.g., *butterfly*). Thus, they have a lexical entry along which their meaning is stored (Sandra, 1990). In the current study, however, only transparent compounds were used in order to be suitable for recombination. Transparent compounds, however, for which the meaning can be derived from their constituents, were shown to be semantically composed, i.e. integrated, on-line during processing. More explicitly, they are associated with a larger N400 than opaque compounds (Koester, Gunter, & Wagner, 2007). Hence, this integration process might be reflected in a comparably large N400 for transparent compounds as for unrelated pairs. This explanation, however, has to acknowledge that Rhodes and Donaldson (2008a) found the reduced N400 also for word pairs being related in an associative and semantic manner which do not form a compound pair (e.g., *lemon – orange*). Besides the possibility that strength of the association matters and that the word pairs used by Rhodes and Donaldson (2008a) might be more strongly associated than the ones used in the current study, it is also possible that the ratio of related and unrelated pairs influenced the results. Lau, Holcomb, and Kuperberg (2013) showed that the reduction of the N400 to a word following a related prime is much larger when the proportion of related pairings is high in contrast to when it is low. As in the study by Rhodes and Donaldson the proportion of related pairs was higher than in the current experiment, this might have enhanced their effect. In sum, although the question why the effect was not observed in the current study cannot be completely resolved, the current results add evidence to the notion that the ease of conceptual integration is influenced by contextual factors such as list composition (e.g., Lau et al., 2013).

The second divergence from the hypotheses relates to the assumption that the N400 in the unitization condition would be reduced during the second presentation due to the conceptual integration during the first presentation mirroring the early old/new effect found during explicit recognition conditions (Bader et al., 2010; Wiegand et al., 2010). However, as already mentioned above, the integration/unitization process from first to second presentation is probably reflected in the amplitude reduction in the late time window. A delayed time course of processing is generally not surprising for word pairs in contrast to single words. Thus, in the current study the pairs were probably processed in a sequential manner (see also Koester et al., 2007, for a late N400 effect during the processing of compounds). Note that the earlier effect (in the N400 time window) in the studies by Bader et al. (2010) and Wiegand et al. (2010) was found under task conditions in which processing speed was pushed by the requirement to respond as quickly as possible. This might explain the apparent discrepancy between the findings.

The study phase ERPs as a whole suggest that the ease of conceptual processing is sensitive to contextual influences. However, if integration was successful once, conceptual processing is facilitated in a shortly following subsequent presentation of the same stimulus. Moreover, conceptual integration has taken place for both conditions. However, it seems delayed in the unitization condition.

7.4.3 Test Phase ERPs

The Early Old/New Effects

Analyses of the early time window showed that neither compound nor unitization word pairs were associated with an early old/new effect. The only effect to be observed were generally more positive going ERPs for the compound condition than the unitization condition at left/mid-line electrode sites. This constitutes a replication of the effect found in the study phase.

The lack of early old/new effects is striking as both kinds of word pairs have previously been found to elicit reliable early old/new effects (Rhodes & Donaldson, 2007; Bader et al., 2010). Moreover, these findings have been explained with the unitized nature of the stimuli (Rhodes & Donaldson, 2007) or the unitizing way of encoding (Bader et al., 2010) leading to an enhancement of familiarity-based remembering. However, little has been changed from these studies to the current experiment in the nature of the stimuli. The only variation was the use of transparent instead of opaque compounds (see above) in the compound condition. Although this could mean that the compound word pairs were not perceived as unitized because transparent compounds have to be integrated during online processing (Koester et al., 2007), this is unlikely the reason for this discrepancy of the results as the study phase data clearly shows that integration was successful from first to second presentation. There is no obvious reason why the studied pairs should be disintegrated again during the test phase. Moreover, similar to the stimuli in the Rhodes and Donaldson (2007) study, the compound word pairs were rated as highly unitizable in the pre-experimental rating. Thus, contextual or strategic influences such as list composition have more likely caused the absence of the effect, comparably to the study phase.

A similar picture emerges for the unitization condition. It could be the case that the unitization encoding had not been effective possibly because of the presence of the pre-experimentally unitized word pairs from the compound condition. However, the positivity associated with the newly unitized word pairs during the second presentation in the study phase strongly suggests that some kind of integration process has taken place leading to facilitated conceptual processing. Moreover, if a less optimal unitization process would have been the reason for the lack of the effect, at least the word pairs which were better unitized, as indicated by the study phase ratings, should have shown the effect. This, however, was not the case. Hence, together with the results for the compound condition, this speaks again for a contextual or strategic component influencing the early old/new effects. Possible contextual or strategic influences will be elaborated on in the following.

The largest change from the preceding studies to the current one is the inter-mixed presentation of the two types of word pairs. As is evident from the significant difference in amplitude size between the conditions, participants presumably have assessed this difference in some way during the recognition test. This effect might have been elicited because participants perceived the compound pairs relatively more familiar than the novel units. Nevertheless, given that familiarity is widely considered as an automatic process (see Yonelinas, 2002, for a review), it is still surprising that the studied stimuli were not more familiar than the unstudied stimuli. However, a few ERP studies suggest that task demands can have an effect not only on recollection but also on familiarity. For example, Ecker and Zimmer (2009) compared old/new effects for exact repetitions of studied object pictures (same) and pictures of different exemplars of studied objects (different) under two different retrieval conditions. In both conditions, same pairs had to be classified as 'old' and new pairs as 'new'. In the exclusion condition, participants had to classify different pictures as 'new' and no mid-frontal old/new effect was found for different pictures but only for same pictures. In contrast, in the inclusion task, in which participants had to classify different pictures as 'old', there was a smaller but reliable old/new effect also for different pictures.

Thus, perceptually changed pictures were only assessed as familiar when this was in accordance with the task. Similar results were obtained in a study with faces in which some of the studied faces changed the facial expression from study to test. Faces with a changed expression elicited only an old/new effect when they had to be classified as ‘old’ (Guillaume & Tiberghien, 2013). These results together with findings that the mid-frontal old/new effect is not observed under implicit memory conditions (Küper et al., 2012) support the notion that it reflects the assessment of familiarity which takes task demands into consideration rather than a pure context-independent measure of stimulus familiarity. In the current experiment, the assessment of familiarity was probably not influenced by the task instructions, but rather the salience of specific stimulus characteristics. In most recognition memory test phases, the stimulus set is homogeneous and the most prominent characteristic of the items is the study status as it was also the case in the Rhodes and Donaldson (2007) study where at least most of the pairs were related. Similarly, the most prominent feature of the test stimuli in the Bader et al. (2010) study was the conceptual fluency of the pair which coincided with the study status of the pair leading to the emergence of the early parietal old/new effect. In the current experiment, however, although the pairs in the unitization condition have presumably been unitized during study, the most salient feature of the pairs was probably their pre-experimental familiarity which, however, is not diagnostic. At the same time, the change in familiarity from study to test would discriminate reliably between old and new items, i.e. would be diagnostic. However, this feature was not salient enough, i.e. was not recognized as such, and therefore lost its diagnosticity.

The Left Parietal Old/New Effect

A reliable left parietal old/new effect in the late time window could be observed in both conditions with the effect being slightly more pronounced in the compound condition. Although a recollection-related effect in the unitization condition is contrary to the Bader et al. (2010) study, it was expected based on the results by Wiegand et al. (2010) and the consideration that two presentations during the study phase boost recollection at test (Opitz, 2010a). This argument holds independently of condition which is why a left parietal old/new effect was also expected for the compound pairs (see also Rhodes & Donaldson, 2007). Furthermore, as familiarity was apparently not diagnostic for a correct recognition decision, recollection was even more important to solve the task. Thus, these findings add to the evidence that recollection is important for associative memory (e.g. Donaldson & Rugg, 1998; Jäger et al., 2006, see also chapter 2.2.1).

7.4.4 Conclusion

The behavioral findings suggest that the higher the degree of unitization, the faster are the response times during test which is in line with the interpretation that the response times are an indicator of conceptual fluency. The study phase ERPs showed that conceptual integration takes place for both types of pairs although processing is delayed for novel concepts. Regarding the results in the bigger context of previous studies, they add evidence to the notion that the ease of conceptual processing is influenced by external factors which are not directly relevant to the processing of meaning such as list composition and time pressure during task completion. Similarly, the early old/new effects associated with familiarity do not seem to be purely determined by the characteristics and learning history of the stimulus but also contextual influences such as the salience of diagnostic features.

CHAPTER 8

Experiment 4

8.1 Introduction

The influence of unitization on associative recognition memory has so far been investigated using predominantly verbal stimuli (e.g., Quamme et al., 2007; Rhodes & Donaldson, 2007; Bader et al., 2010). In these studies, word pairs are combined in such a way that they denote a single concept as in Experiment 2 and 3. Especially, studies investigating unitization as encoding strategy using pre-experimentally unrelated stimuli covered solely the verbal domain. The finding of the early parietal old/new effect (Bader et al., 2010; Wiegand et al., 2010) which was associated with a form of familiarity that emphasizes conceptual processing suggests an important role for the creation of a new meaning during unitization. The few exceptions outside the verbal domain comprise studies using face stimuli (e.g., Yonelinas et al., 1999; Jäger et al., 2006) and object-color-binding (e.g., Diana et al., 2008). Face stimuli are idiosyncratic as humans are highly specialized in perceiving faces as a unit and object-color-binding involves binding of an object and an intrinsic feature. Thus, participants do not have to create a novel unit out of previously self-contained entities.

Compelling evidence for the influence of unitization on recognition memory in a non-verbal domain comes from studies investigating memory for scene-like stimuli. The instruction of imagining two related words in an interactive manner during encoding (e.g., *table* and *fork* interacting) was shown to boost later familiarity-based recognition (Rhodes & Donaldson, 2008b) in contrast to a separate item imagery instruction. However, imagery instructions can only poorly be controlled. Related evidence comes from Kriukova (2012) who used thematically related word pairs (e.g., *taxi – luggage*). These word pairs exhibit a situational uniqueness meaning that a taxi and luggage can easily be imagined in a coherent scene because they often occur in the same context. Therefore, they are supposed to be perceived in a more unitized manner. Kriukova (2012) found that recognition memory for thematically related pairs is associated with a mid-frontal old/new effect and a reduced left parietal old/new effect. Although Kriukova (2012) used word pairs, the unitization mechanism does not originate from building a concept but presumably from creation of a scene. Crucially, both aforementioned studies used word pairs which were pre-experimentally related. Thus, it is so far unknown whether unitization of arbitrary item combinations is also possible for two discrete pictorial items and can enhance familiarity-based recognition memory comparably to verbal stimuli.

Therefore, the current study's aim was to extend previous research on unitization of previously unrelated items by employing pairs of object pictures creating novel scenes. A scene was expected to be processed in a more unitized manner than two separate and independent objects. This manipulation was intended to be consistent with the studies reported in this thesis in the verbal domain. Thus, the objects did not have a prior associative or semantic relationship and unitization was supposed to take effect during encoding. The scene manipulation does not only transfer the unitization paradigm to the pictorial domain but also ex-

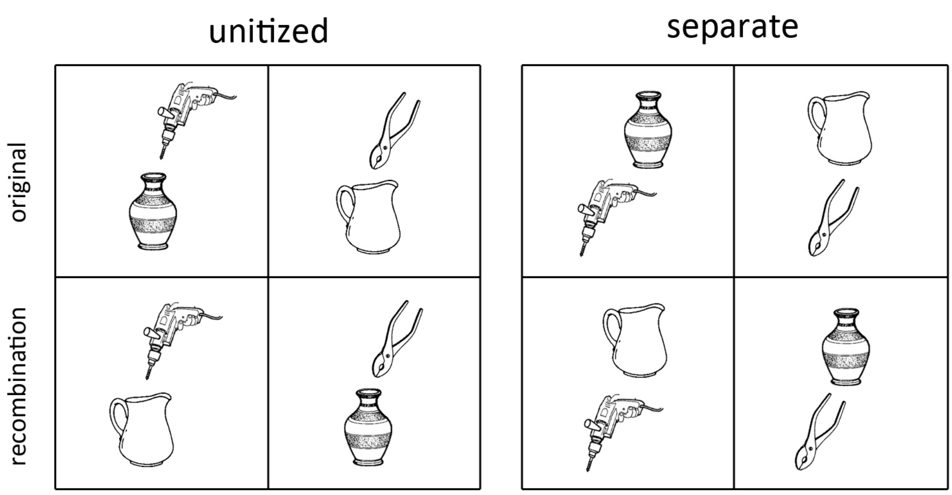


Figure 8.1.: Example stimuli in the unitization and separation group. Displayed are two original pairs each (upper panel) which were grouped to form recombinations (lower panel).

tends the notion of a unit from contiguous items to a unitized multi-item array. A scene was created by arranging the objects in a spatial layout which is coherent to prior location-based associative knowledge (Gronau, Neta, & Bar, 2008). This means that a specific object can demand other objects in a specific spatial relation to itself. For instance, other objects are normally put *on top* of a table whereas they are put *inside* a box. Evidence for the relevance of such spatial relationships during object recognition comes from priming studies which showed priming effects when the target appeared in a spatially coherent position to the prime (e.g., a dressing-table mirror on top of a dressing-table) compared to an incoherent position (e.g., mirror below the dressing-table; Gronau et al., 2008). Similar priming effects can be observed when spatial coherence is established by an implied action connecting two objects such as a screwdriver pointing towards a screw (C. Green & Hummel, 2006). Thus, these studies suggest that spatial coherence makes participants perceive a pair of objects more readily as an integrated scene, i.e. as a unit.[1] Thus, the scene-like pairs in the unitization condition were arranged in a spatially coherent way or as if they were interacting. This condition was opposed to a separation encoding condition which was implemented by reversing the positions of the two objects resulting in a spatially incoherent arrangement (see Figure 8.1).

Encoding condition was realized as a between-subjects factor to prevent a spill-over between the two conditions. Participants might develop a general tendency to perceive the two objects as a scene irrespective of the actual arrangement. During study, object pairs were presented only very briefly (400 ms) to place stronger weight on the advantage of a unitized processing. A relatively short presentation time should be sufficient to extract the gist of a scene-like arrangement whereas separated unrelated objects lack this kind of information. As this manipulation rendered the memory task rather difficult, the experiment was split into several short study-test blocks and an intentional encoding instruction was employed. To further facilitate processing of the pairs during the

[1]It has to be noted that the priming effects were only found when the two objects were also thematically related. For unrelated pairs (e.g., a screwdriver pointing towards a cigarette) the effect is sometimes even reversed (C. Green & Hummel, 2006). However, in this kind of priming paradigms where semantically related pairs are included participants are likely to form expectations regarding the semantic features of a target. This might lead to inhibitory effects when these expectations are violated. Thus, semantic effects could have counteracted the spatial effects (see Gronau et al., 2008, for a similar discussion).

short presentation time participants saw each single object once in an item familiarization phase at the beginning of the experiment at which point of time participants were not aware of the upcoming memory task. At test, participants had to discriminate between same and recombined pairs. In order to isolate effects of unitization on familiarity, a response-deadline procedure was used. Each participant was tested under two different testing conditions, a speeded and a nonspeeded response procedure. The nonspeeded condition generally allows familiarity and recollection to occur. However, the speeded condition is assumed to minimize the contribution of recollection as recollection is a rather slow-acting process. Therefore, performance in the speeded condition can be regarded as an estimate of familiarity-based recognition performance (see Section 1.2.2). Previous studies showed that recollection-based responses are very unlikely before 800 ms after stimulus onset (e.g., Hintzman & Curran, 1994; Mecklinger et al., 2010).[2] The response deadline in the current experiment was set to 900 ms accounting for the increased perceptual complexity in a two-object display.

The response deadline manipulation was expected to influence performance in such a way that the speeded condition should reduce accuracy. Moreover, it was expected to interact with the encoding group manipulation. Although the short presentation time during the study phase was expected to generally favor the unitization group, the performance advantage of this group was hypothesized to even further increase under speeded response conditions. This was expected because only in the unitization condition familiarity is assumed to contribute to recognition whereas in the separation condition recollection is required to remember the association between the pairs. A stronger reliance on familiarity should also lead to faster responses in the unitization than in the separation group under nonspeeded conditions.

8.2 Methods

8.2.1 Participants

Forty-eight participants recruited from the student population at Saarland University took part in the experiment and were randomly assigned

[2]Although recollection has probably occurred at that point of time considering the timing of the left parietal old/new effect (500–800 ms), responses based on this information are unlikely to be made because post-retrieval, decision, and motor planning processes take additional time.

to the unitization group (14 female, 10 male) and separation groups (15 female, 9 male). In the separation group, data from one additional participant was excluded from analysis due to a PR score < 0 in the nonspeeded condition. Mean age of the remaining participants was 22.21 (range: 18–30) in the unitization group and 20.58 (range: 18–29) in the separation group. Participants had normal or corrected-to-normal vision and gave informed consent. They received 8 Euros/hour for participation. The experiment was approved by the local ethics committee of Saarland University.

8.2.2 Stimuli

The stimulus set consisted of 160 black-and-white line-drawings of objects, animals, and persons taken from the picture set by Snodgrass and Vanderwart (1980) and the database of the International Picture Naming Project (Szekely et al., 2004). The pictures were selected in order to form pairs of objects which normally do not occur in the same context but which can be arranged in a spatially coherent configuration. The pairs were assembled in groups of two to five pairs to build recombinations (see Figure 8.1). For example, in a group of three pairs the pairs AB, CD, and EF, were recombined to AF, CB, and ED. Each original pair could be presented in the old or recombined condition at test. Correspondingly, the same version (for old pairs) or the recombination (for recombined pairs) were presented during the study phase. Assignment of pairs to the recombined and old condition as well as to the speeded and nonspeeded condition was counterbalanced across subjects resulting in four different lists (see Appendix A.6 for a full list of stimuli).

8.2.3 Procedure

The experiment started with the item familiarization phase. In this part of the study, participants were presented with all single objects one at a time. They were instructed to make an indoor/outdoor decision for each object. A trial started with a 750 ms fixation cross followed by a blank screen of 250 ms. Then the pair appeared on the screen until the participant responded. Responses were given by pressing the keys 'f' and 'j' using the index fingers of both hands. Assignment of indoor and outdoor responses to keys was counterbalanced across participants. In case an object could not be recognized participants had the possibility to press the space-bar in order to see the name of the object for 1000 ms.

Analysis of the responses in the item familiarization phase revealed that the mean number of objects which could not be recognized at first glance in the unitization group ($M = 3.71$; range: $0 - 13$) and in the separation group ($M = 2.96$; range: $0 - 13$) did not differ ($t < 1$).

In the main experiment, encoding condition was manipulated between subjects. In both groups, the speeded condition always followed the nonspeeded condition as piloting suggested that participants had difficulties switching to a slower response mode after having got used to the speeded response timing. The whole procedure was split into two study-test blocks for both conditions. Each block consisted of ten study and ten test trials. The study phase instruction was to remember the pairs for a later memory test and to be highly attentive as presentation time would be very short. Each trial started with a blank screen of 1200 ms followed by a 500 ms fixation cross and a further 200 ms blank screen. Then the pair was presented for 400 ms. At test, participants had to discriminate between old and recombined pairs. Each trial began with a sequence of a 500 ms blank screen, a 500 ms fixation cross, and 200 ms blank screen. The pair was presented for 1000 ms. In the speeded condition, subjects were instructed to respond before the offset of the pair and a warning tone was played if the response was slower than 900 ms (participants were not aware of the deadline being slightly earlier than picture offset). If they would hear the tone, participants were instructed to try to respond faster. In the nonspeeded condition, if required, participants had additional 3500 ms time to respond during the display of a blank screen. Responses were made by pressing the keys 'f' and 'j' with the index fingers of both hands. Assignment of responses to keys was counterbalanced across subjects.

8.2.4 Data Analysis

Memory performance was assessed by hit and FA rates as well as the percentage of time-outs (no response was given). Additionally, the combined performance measure PR and the estimate of response bias BR were calculated based on corrected hits and FA rates as suggested by Snodgrass and Corwin (1988). Moreover, reaction times for correct responses were analyzed. Trials were excluded from all analyses if the reaction time was < 300 ms which resulted in the exclusion of one trial each for the unitization and separation group in the nonspeeded condition and three trials for the separation group in the speeded condition. Inferential statistics were performed using a MANOVA with the factors of Speed (nonspeeded, speeded) and Group (unitization, separation) as well as the factor of Pair Type (old, recombined) if applicable. The significance level was set to $\alpha = .05$.

8.3 Results

As can be seen in Table 8.1, performance was generally better in the nonspeeded than the speeded condition and better in the unitization group than in the separation group. A MANOVA with the factors Speed (nonspeeded, speeded) and Group (unitization, separation) on the PR-scores revealed a significant main effect of Speed ($F(1, 46) = 16.41, p < .001$) and a significant main effect of Group ($F(1, 46) = 5.73, p < .05$), but no interaction ($F < 1$). However, performance was above chance in both speed conditions for the unitization group (nonspeeded: $t(23) = 14.95, p < .001$; speeded: $t(23) = 8.62, p < .001$) as well as the separation group (nonspeeded: $t(23) = 8.04, p < .001$; speeded: $t(23) = 6.91, p < .001$). An analysis of the hit rate with the factors Speed and Group revealed a main effect of Speed ($F(1, 46) = 34.60, p < .001$), but neither a main effect of Group ($p = .14$) nor a significant interaction (F < 1). Analysis of the FA rate yielded only a marginally significant main effect of Group ($F(1, 46) = 3.43, p < .08$), but no other significant effects (F-*values* < 1). Thus, the drop in performance for the speeded condition was mainly driven by a decrease of the hit rate. For the group difference the story is less clear. It seems to be driven by differences in both, hits and false alarms.

Analysis of the percentage of time-outs with the factors Speed, Pair Type, and Group revealed a main effect of Speed ($F(1, 46) = 111.97, p <$

Table 8.1.: Mean response rates, mean proportion of time-outs, and mean Pr- and Br-scores in the nonspeeded and speeded conditions for the unitization and the separation group. Standard errors are given in parentheses. TO = time-out; rec = recombined.

	hit	miss	CR	FA	old TO	rec TO	Pr	Br
				nonspeeded				
unitization	.88 (.02)	.10 (.02)	.65 (.03)	.31 (.03)	.02 (.01)	.04 (.01)	.54 (.04)	.68 (.03)
separation	.84 (.02)	.14 (.02)	.59 (.04)	.39 (.04)	.02 (.01)	.02 (.01)	.43 (.05)	.70 (.03)
				speeded				
unitization	.74 (.03)	.19 (.03)	.49 (.03)	.34 (.03)	.07 (.01)	.17 (.02)	.38 (.04)	.58 (.03)
separation	.69 (.03)	.17 (.02)	.38 (.03)	.41 (.04)	.14 (.02)	.21 (.03)	.27 (.04)	.57 (.03)

.001), a main effect of Pair Type ($F(1, 46) = 22.23, p < .001$), and a marginally significant effect of Group ($F(1, 46) = 3.41, p < .08$). Moreover, significant interactions of Speed × Group ($F(1, 46) = 7.25, p < .05$) and Speed × Pair Type ($F(1, 46) = 16.22, p < .001$) were obtained. No other interactions were significant (*F-values* < 1.58). Following-up the significant interactions, separate MANOVAs with the factors Pair Type and Group were performed for each speed condition separately. In the nonspeeded condition, no significant effects were obtained (*F-values* < 2.25). However, in the speeded condition, a significant main effect of Pair Type ($F(1, 46) = 21.93, p < .001$) and a significant main effect of Group ($F(1, 46) = 5.33, p < .05$) were revealed, but no interaction ($F < 1$). In sum, analysis of the actually given responses suggests generally better performance in the unitization group irrespective of speed condition. However, examination of the time-outs revealed that the separation group more often failed to respond at all when forced to respond very fast.

A MANOVA on the Br-score yielded a significant main effect of speed ($F(1, 46) = 20.57, p < .001$), but no main effect of group and no interaction (*F-values* < 1) showing a more liberal bias in the nonspeeded than speeded condition.

Table 8.2 shows that in line with the speed manipulation, reaction times in the nonspeeded condition were longer than in the speeded condition. Moreover, old pairs were recognized faster than recombined pairs. Correspondingly, a MANOVA with the factors Speed, Pair Type, and Group revealed a main effect of Speed ($F(1, 46) = 204.29, p < .001$), a main effect of Pair Type ($F(1, 46) = 74.98, p < .001$), but no main effect of Group ($F < 1$). Additionally, a significant interaction of Speed × Pair Type was revealed ($F(1, 46) = 50.08, p < .001$). No other interactions

Table 8.2.: Mean reaction times for correct responses in the nonspeeded and speeded conditions for the unitization and the separation group. Standard errors are given in parentheses.

	nonspeeded		**speeded**	
	hit	**CR**	**hit**	**CR**
unitization	1023 (50)	1343 (52)	690 (10)	731 (9)
separation	977 (46)	1316 (63)	679 (11)	747 (12)

were significant (*F-values* < 1). Separate analyses for the two speed conditions showed that old pairs were recognized faster than recombined pairs in the nonspeeded ($F(1,46) = 64.92, p < .001$) and the speeded condition ($F(1,46) = 45.61, p < .001$). Neither main effects of Group nor the interactions were significant in both analyses (*F-values* < 2.63).

8.4 Discussion

The purpose of Experiment 4 was to extend the spectrum of domains in which using unitization as an encoding strategy can enhance familiarity-based recognition memory. In particular, effects of unitization were examined for scene-like pictorial stimuli. Participants had to study pairs of objects which normally do not co-occur. By manipulating the spatial configuration of the two objects, the pair should either be perceived as a scene or as a set of separate objects. Scenes were established by putting objects in a position which is typical for this specific object or by implying an action between the two objects. The separation condition was realized by interchanging the position of the objects thereby disintegrating the scene. In order to increase the efficacy of this manipulation, object pairs were presented only very briefly during the study phase leaving just enough time to extract the gist of the scene – an information which was not available in the separation condition. During the recognition test, a response deadline procedure was applied. In the speeded condition, familiarity is expected to be the primary source of mnemonic information whereas in the nonspeeded condition familiarity and recollection can contribute to recognition memory.

In line with our expectations, performance dropped in the speeded compared to the nonspeeded condition. Interestingly, this difference became only manifest in hit rates but not in false alarm rates. This is surprising as impeding recollection should particularly inflate false alarms (Yonelinas, 2002). However, examination of response bias reveals that participants presumably counteracted this by applying a less liberal response criterion in the speeded condition. Crucially, correct rejection rates dropped, too. Thus, in a state of uncertainty, participants did not respond 'old' as in the nonspeeded condition, however, neither responded they 'new'. Instead, they chose to not respond at all resulting in higher rates of time-outs in the speeded condition. Thus, hit and false alarm rate differences are influenced by this specific behavior in the state of uncertainty and are therefore difficult to interpret in isolation.

In line with my predictions was the generally better performance (higher PR-scores) in the unitization compared to the separation group. The short presentation time during study was intended to favor the unitization group over the separation group. A scene-like configuration provides the possibility to extract the gist of the scene in very short time. In contrast, such kind of information can less likely be found in an arrangement of separate objects. An alternative explanation for better performance in the unitization group could be that the scene-like arrangement has triggered the establishment of additional associations (e.g., stories are more easily made up for scenes) and by this has enhanced recollection. However, the performance advantage for the unitization group was not diminished under speeded response requirements which suggests that it cannot fully be explained by recollection of additional associations. Thus, although the finding is less clear than expected (a greater group difference in the speeded condition), within the dual-process framework it can hardly be explained without enhanced familiarity for the unitization compared to the separation group. The expected interaction was presumably not observed because there was not enough recollection in the separation group to compensate for the lower level of familiarity during nonspeeded responding (see Diana et al., 2008, for similar results). It is possible that recollection was generally at a very low level because of the short study phase presentation.

The finding of lower false alarm rates in the unitization group lend further support for this notion because differences in false alarms are generally associated with differences in familiarity as already argued above (Yonelinas, 2002). The most compelling evidence, however, comes from the analysis of the time-outs. When forced to respond fast, participants in the separation group chose not to respond at all more often than those in the unitization group. This implicates that mnemonic information in a quality sufficient to make a decision was available earlier in the unitization group than in the separation group in line with enhanced familiarity.

Contrary to our expectations, a difference in reaction times was not found. However, if it holds true that recollection generally played a minor role during this task and the results mainly reflect differences in familiarity, it is not surprising that there was no difference. A speeding-up of responses would presumably go along with higher reliance on familiarity and at the same time less reliance on recollection. However, if the influence of recollection is generally minimal in both groups, reaction time differences cannot necessarily be assumed.

A general drawback of the response-deadline procedure is that the actual contribution of familiarity and recollection under speeded and nonspeeded response conditions cannot be completely controlled. Some responses in the speeded condition are possibly based on recollection (Yonelinas, 2002). Thus, a criticism of the familiarity interpretation of the current results could be that recollection was faster in the unitization group leading to more recollection which in turn boosted performance. However, I consider this explanation as unlikely for two reasons. First, given the complexity of the visual display and previous ERP research (Mecklinger et al., 2010), the 900 ms deadline should have been successful to reduce recollection-based responses to a minimum in both groups. Second, the reaction times in the nonspeeded condition are not suggestive of speeded recollection due to unitization. If anything, they suggest the opposite. However, it could still be that speeded recollection in the unitization group was induced by the speeded response requirements. Thus, a replication of the findings with another method would clearly strengthen the results.

Assuming the response-deadline procedure was effective in impeding recollection, the pattern of results suggests that familiarity for a pair of objects is boosted when they are presented in a coherent spatial configuration, i.e. in a unitized manner, in contrast to an incoherent configuration. This implies that familiarity enhancement due to unitization of two previously discrete entities by means of an encoding instruction is not restricted to the creation of a novel concept. This is in line with previous findings on thematically related word pairs (Kriukova, 2012) and interactive imagery (Rhodes & Donaldson, 2008b). However, as these studies used pre-experimentally related pairings, the current study extends these findings by showing complementary effects using pre-experimentally unrelated items.

Moreover, the current results imply that the concept of unitization is not limited to the formation of a novel contiguous entity such as a novel compound word pair. A scene or the action depicted in a scene (e.g., *drill targets the vase*) can seemingly also induce familiarity. This is in line with the notion that unitization is not a dichotomy but rather a continuum (Yonelinas et al., 2010) with the current implementation probably being located somewhat away from the end point. If the current results can be substantiated in the future they are further evidence against a one-to-one-mapping of familiarity and item memory (e.g., Aggleton & Brown, 2006).

CHAPTER 9

General Discussion

This thesis addressed open questions with respect to retrieval processes involved in recognition memory for different types of units. This issue is highly relevant within dual-process models of recognition memory as many models assume that familiarity-based recognition is only possible for single items or unitized associations (e.g., Yonelinas, 2002; Aggleton & Brown, 2006; Henke, 2010), but not for arbitrary associations. Unitization, i.e. the integration into a coherent whole, can be regarded as a continuum (Yonelinas et al., 2010) on which different degrees of unitization can be assumed. Although previous studies investigating the effects of unitization on associative recognition memory have implemented different degrees of unitization in their experimental designs (e.g., Giovanello et al., 2006; Rhodes & Donaldson, 2007; Quamme et al., 2007), implications of this aspect have largely been neglected in the literature. However, this seems necessary as especially processes during retrieval turned out to vary according to the degree of unitization (Wiegand et al., 2010).

The main focus of this thesis was placed on novel units, i.e. associations which were unitized during the study phase encounter by means of a specific encoding strategy. In contrast to remembering pre-existing unitized associations (e.g., compound word pairs) or single items (e.g., single words), the creation of a novel unit establishes a new link within a specific episode. Learning links between previously not associated item combinations during only one encounter is of particular interest as it is a core function of episodic memory. In the current work, retrieval processes were examined in order to dissociate them from those being involved in recognition of non-unitized associations, pre-existing items and pre-experimentally unitized associations. Moreover, the goal of the final study was to extend the range of the unitization continuum by examining unitization of scene-like pictorial stimuli.

9.1 Summary of Findings

9.1.1 Experiment 1

The study by Wiegand (2009) investigated the effects of a definition encoding instruction on associative recognition memory. Definition encoding (e.g., VEGETABLE BIBLE = A book which is consulted by hobby gardeners.) is intended to foster unitization of previously unrelated word pairs. Recognition was tested for four different kinds of word pairs: same, reversed, recombined, and new pairs. Same and reversed pairs had to be classified as 'old' whereas recombined and new pairs had to be classified as 'new'. The results revealed faster reaction times for same than reversed pairs. This was interpreted as an indicator for facilitated conceptual processing for the novel units in contrast to the disrupted units. However, this finding can also be explained by a mere perceptual effect: facilitated processing could have been induced by the exact repetition of the study cue in the same condition in contrast to reversed pairs, which were not identical repetitions of the study phase pair. Thus, the principal goal of Experiment 1 was to rule out this explanation in order to substantiate the suitability of the design for Experiment 2. Participants studied the same set of word pairs as separate lexical items which had to be inserted into sentence frames (e.g., VEGETABLE BIBLE – This ___ was already mentioned in the ___). This encoding instruction was intended to minimize unitization of the pairs. The results of Experiment 1 were directly compared to the behavioral data of the Wiegand (2009) study revealing that in contrast to the definition group, reversed pairs were recognized as fast as same pairs when studied in the sentence encoding condition. However, accuracy was slightly lower for reversed than same pairs irrespective of encoding instruction.

9.1.2 Experiment 2

Previous studies suggested that associative recognition memory can be mediated by brain structures outside the hippocampus, presumably in the PrC, when word pairs are studied in the definition encoding condition (Quamme et al., 2007; Haskins et al., 2008). This corresponds to findings for familiarity-based retrieval of pre-existing unitized associations (Giovanello et al., 2006; Ford et al., 2010) and single items (e.g., Henson et al., 2003; Montaldi et al., 2006). However, these studies did not directly examine which brain structures are involved during the retrieval of unitized word pairs in healthy participants. Moreover, the results of two ERP studies suggest that familiarity is associated with different neural correlates when novel units are recognized in contrast to pre-existing items. Thus, there were two main goals of Experiment 2. One of the objectives was to investigate the neural network underlying the retrieval of novel concepts compared to arbitrary associations. The second aim was to dissociate the brain regions involved in familiarity for novel units and single items. Thus, definition and sentence encoding was compared in a between-group design. At test, participants were presented with same, reversed, recombined, and new pairs (as in Experiment 1). Familiarity for novel units and single items was dissociated by comparing same and reversed pairs because for reversed pairs the unit was assumed to be disrupted. Analysis of the reaction times replicated the findings from Experiment 1 showing faster responses for same than reversed pairs in the definition group but not in the sentence group. However, in contrast to Experiment 1, there was also a selective decrease in accuracy for reversed pairs in the definition group. Analysis of the imaging data revealed a strong recruitment of a network normally associated with recollection in the sentence group. Among others, I found activation in the posterior cingulate, the ventral PPC, and the hippocampus. This network was engaged to a comparable extent for same and reversed pairs. In contrast, in the definition group, recruitment of recollection-related areas was considerably reduced. Instead, same as well as reversed pairs engaged the dorsal PPC. Specifically associated with recognition of same pairs in the definition group was a region in BA 10 in the mPFC. Conversely, solely activated by reversed pairs was one cluster in BA 45 in the left IFG.

9.1.3 Experiment 3

Experiment 3 was designed to directly compare novel conceptual units (unitization condition) to pre-existing units (compound condition) as these two types of pairs are assumed to differ in the degree of unitization and were previously associated with two different early old/new effects (Rhodes & Donaldson, 2007; Bader et al., 2010). Therefore, only novel conceptual units were expected to elicit an early parietal old/new effect whereas pre-existing units were assumed to elicit an early mid-frontal effect. During study, each word pair was studied twice allowing to compare ERPs to the pairs during the first presentation to those during the second presentation. By this, I aimed to establish a link between the early parietal old/new effect and the N400 during implicit memory conditions. During study, participants had to rate the fit of the description or definition which was provided along with the pairs. These ratings were highly consistent across presentations. Moreover, they were slightly higher for pre-existing units than for novel units. At test, participants had to discriminate old, recombined, and new pairs. Performance was better in the compound than in the unitization condition. Moreover, the higher the degree of unitization, the faster were the responses. This was not only evident in faster reaction times in the compound condition, but also in a speed-up for plausible compared to implausible pair-definition combinations as indicated by the study phase ratings. The N400 during study was reduced in the compound compared to the unitization condition only during the second presentation. Within the unitization condition, a reduction of the ERPs during the second presentation compared to the first presentation was only observed in a later time window (600–800 ms) whereas this was the case in the compound condition already during the early time window (380–580 ms). Contrary to my predictions, an early old/new difference at test was revealed in neither of the conditions, but the compound condition was associated with generally more positive going waveforms than the unitization condition. Reliable left parietal old/new effects were observed in both conditions.

9.1.4 Experiment 4

The aim of the final experiment was to extend the use of unitization as encoding strategy to the pictorial domain. Units were created by the arrangement of two unrelated objects in a scene-like configuration (unitization group). By this, the novel unit was not a novel item as in the previous experiments but a multi-item array extending the continuum of unitization. In a between-group design, this condition was contrasted with a condition in which the two objects changed positions, which was intended to disintegrate the scene (separation group). By applying a response-deadline procedure, effects on familiarity could be identified in the speeded condition. The unitization group was better than the separation group in the speeded and nonspeeded condition. Moreover, participants in the separation group more often failed to respond at all in the speeded condition. There were no group differences in reaction times.

9.2 Implications

In the following, I discuss implications from the results of the experiments reported in this thesis. Before addressing different aspects in detail, I shortly elaborate on a more general issue which is relevant for the subsequent considerations. Until now, few studies have investigated familiarity-based memory for novel units. With respect to the brain regions involved, these studies suggest an important role of the PrC in memory for unitized associations in a comparable way to single items. However, they either allow only for inferences about the encoding phase (Haskins et al., 2008; Staresina & Davachi, 2008) or do not allow for a differentiation between encoding and retrieval processes at all (Quamme et al., 2007) as lesion studies cannot isolate the effects to one or the other. In line with the transfer-appropriate-processing account which states that performance in a memory task depends on the appropriateness of the encoding task (Morris, Bransford, & Franks, 1977), it is assumed that neural activity at encoding and retrieval are at least overlapping (Rugg, Johnson, Park, & Uncapher, 2008). This is in particular the case for material specific activation and for the structures in the MTL. The latter is most evident in the MTL memory models described in Section 1.3 which do not differentiate between encoding and retrieval (e.g., Aggleton & Brown, 2006; Diana et al., 2007; Ranganath, 2010; Norman & O'Reilly, 2003). It is conceivable that the memory components housed in the MTL are directly related to the representation of the to-be-remembered stimulus and are therefore common to encoding and retrieval. However, it is also clear that there must be processes which are specific to encoding or retrieval, respectively, such as attention to the to-be-encoded event or the control processes necessary for intentional retrieval (Rugg et al., 2008). Therefore, it is crucial to investigate both, encoding and retrieval. Moreover, when interpreting the results, it is important to distinguish between different processing stages.

I start with a discussion about the engagement of recollection during associative recognition memory focusing on the role of the hippocampus. Thereafter, I shed light on the different aspects of familiarity which are relevant during recognition of unitized associations.

9.2.1 Recollection

The results from Experiment 2 clearly show a strong involvement of a network usually associated with recollection, especially the hippocampus, when arbitrary associations have to be retrieved. This is consistent with previous ERP (e.g., Donaldson & Rugg, 1998; Bader et al., 2010) and fMRI studies (e.g., Giovanello et al., 2004; Ford et al., 2010). Moreover, behavioral (Experiment 1 and 2) as well as imaging results revealed a flexible recollection process in the sentence condition. Brain responses and overt behavior were highly similar for same and reversed test cues. This is consistent with a previous fMRI study (Giovanello et al., 2009) which showed flexibility of hippocampal retrieval when word pairs were encoded within sentences. Moreover, this outcome would be predicted by the computational model proposed by Norman and O'Reilly (2003). According to this account, the single parts of one episodic memory trace or association, which are represented in the input layer of entorhinal cortex (EC), are linked to each other with recurrent connections in region CA3 of the hippocampus proper. A re-representation of the CA3 representation can be found in region CA1. Crucially, this CA1 representation has back-connections to each representation of the single parts in the output layer of EC. As the CA3 representation consists of recurrent connections, each partial cue can reactivate the whole pattern in CA3 and via activation in CA1 all constituents can be reactivated in the output layer of EC. This implicates that reversing the test cue does not have any detrimental effects on the ability of the hippocampus to retrieve the original study cue as reflected in the parallel finding of hippocampal activation for same and reversed pairs in the sentence group in Experiment 2.

Consistent with previous comparisons of item and associative recognition memory (Giovanello et al., 2004), I found reduced engagement of the hippocampus in the definition group of Experiment 2 compared to the sentence group. The findings by Quamme et al. (2007) already showed that the hippocampus is not necessary to remember novel units. The results from Experiment 2, however, implicate that the recollection network including the hippocampus plays only a limited role in recognizing novel units also in cases where it is generally available as in healthy young participants. This is in contrast to the findings from Experiment 3 where recognition of novel conceptual units was associated with a left parietal old/new effect and other studies investigating the retrieval of unitized associations which did not find a reduced involvement of recollection (Wiegand et al., 2010; Rhodes & Donaldson, 2007, 2008b). This raises the question when and how recollection is impeded. One possibility is that the involvement of the hippocampus during retrieval is already determined during encoding. Given that a unitized association is primarily processed in the PrC and not in the hippocampus during encoding (Haskins et al., 2008), no hippocampal representation of the association is established. In this case, the hippocampus is just not able to retrieve the association. In the studies mentioned above which showed recollection for unitized associations, the study conditions slightly differed from those in Experiment 2. For instance, each pair was studied twice in the study by Wiegand et al. (2010). Whereas during a single study trial, conceptual integration mediated by the PrC might be emphasized, a second presentation of the study pair might enhance recollection in the following way: having already integrated the unitized pair during the first presentation, processing can proceed one step further during the second presentation and the hippocampus can establish links between the novel unit and the definition and/or other study details. According to this interpretation, the observed recollection effects reflect recollection for study details and not recollection of the association itself. Another explanation can be found in the framework postulated by van Kesteren et al. (2012) which claims that whenever incoming information is perceived as congruent to pre-existing knowledge, hippocampal involvement is inhibited by the mPFC. Thus, the selective mPFC activation for same pairs in the definition group would be consistent with this explanation. This view would allow for the opportunity that unitized associations could have been initially encoded also in the hippocampus. However, hippocampal involvement was inhibited only during retrieval because the conceptual integration during study rendered the pairs congruent to pre-existing knowledge. The study by Haskins et al. (2008) cannot adjudicate between these two accounts as it reported hippocampal activation neither in the sentence nor in the definition condition. Hence, it remains open to future research to determine the boundary conditions of when recollection is engaged in cases where it is not necessarily needed in order to make a correct recognition decision.

9.2.2 Familiarity

The following section starts with considerations about the functional significance of different brain regions associated with familiarity, focusing first on the MTL and turning then to structures outside the MTL which might subserve functions specific to retrieval. Subsequently, I discuss different aspects in relation to familiarity such as conceptual fluency and contextual influences.

Engagement of the MTL

With respect to the PrC, the results from the current thesis are somewhat ambiguous as I did not find any evidence of a significant PrC response to any of the pair types in Experiment 2. Nonetheless, the current results do not imply that the PrC is not involved during recognition of novel units. As neither single items nor the novel units were associated with a deactivation in the PrC, susceptibility induced signal loss and low power are likely reasons for this null finding. The role of PrC in memory for units is nevertheless an interesting issue. Especially, as the better performance in the unitization group compared to the separation group under speeded response conditions in Experiment 4 constitute first evidence for familiarity-based memory for multi-item arrays. In keeping with the prevailing theories of MTL memory functions, these results indirectly speak for a representation of these multi-item arrays in the PrC (but note that familiarity for the scenes could have also been induced by an attribution process not mediated by the PrC, see below). In the models described in Section 2.3, the claim that the PrC is involved in memory for unitized associations is motivated by the reasoning that unitized associations are processed as single items (Diana et al., 2007; Ranganath, 2010; Yonelinas, 2002; Yonelinas et al., 2010). This is in line with another account for the functions of the MTL. The representational-hierarchical view (RHV, e.g., Cowell, Bussey, & Saksida, 2010) provides a more general conceptualization of MTL functioning. It rejects the idea of specialized processes within the MTL and puts forward the notion that the subregions within the MTL are differentially suitable for different kinds of representations, regardless of the task. Along the ventral-visual stream (VVS) from the most caudal regions in the primary visual cortex to the most anterior region in the anterior temporal lobe, complexity of representations steadily increases. Thus, according to the RHV, the PrC is best suited to represent complex conjunctions of many features whereas more upstream regions in the VVS represent more simple conjunctions or single features. Crucially, the PrC is able to discriminate very similar objects containing identical features as it recognizes the specific configuration.

Higher up in the hierarchy, the hippocampus is best suited to represent contextual, spatial or relational information. Evidence for the PrC's role in object representation comes from studies with monkeys (Bussey, Saksida, & Murray, 2002) and rats (e.g., McTighe, Cowell, Winters, Bussey, & Saksida, 2010), but also from studies with human MTL patients. For instance, Barense et al. (2005) compared patients with selective hippocampal lesions and patients with more extensive MTL lesions in a task where they had to learn which of two objects was the target to choose. Both patient groups performed at the control group's level when feature ambiguity between the objects was minimal. With high feature ambiguity the target could only be identified based on the feature conjunction. In this condition, hippocampal patients still performed within the normal range but the MTL patients showed a significant drop in performance. This implicates that the MTLC, most likely the PrC, supports identification and recognition of complex objects. K. I. Taylor et al. (2006) provide complementing fMRI evidence that the PrC is crucial for the integrated representation of objects and associated conceptual information. Participants had to make congruency judgments in either a crossmodal condition (e.g., a picture of a cat and the sound "meow") or a unimodal condition (e.g., two parts of a picture of a cat). The PrC was more involved in the crossmodal than in the unimodal condition and was more activated for incongruent in contrast to congruent crossmodal pairs. Congruent combinations seem to match a sharp representation of the concept whereas incongruent combinations activate a larger and more ambiguous set of features. In line with the RHV, these results suggest that the PrC serves an amodal integration hub which can represent complex feature configurations on the object and the conceptual level. Thus, it is a likely candidate to produce a memory signal which is specific to these kinds of configurations. Given that the scene-like stimuli used in Experiment 4 could be recognized under speeded response requirements because they were represented in the PrC, this finding would have to be incorporated into the accounts of PrC function described above. However, the multi-item arrays are neither single objects nor are they circumscribed concepts. Animal studies which are taken as support for the RHV partly used multi-item displays, too (e.g., Saksida, Bussey, Buckmaster, & Murray, 2007). Thus, object in this sense might rather refer to any stable configuration of multiple features which is processed independent of context. It is also possible that participants extracted concepts about specific actions out of the scenes such as *drill points to* *vase*. If further research can substantiate the results from Experiment 4 and can show that the PrC is involved in familiarity for scenes, both explanations would challenge a mapping of perirhinal familiarity to item recognition (e.g., Aggleton & Brown, 2006).

Downstream from the MTL

As already stated above, processes which are specific to retrieval might be mediated by structures outside the MTL. This section focuses on "processes downstream from those responsible for computing familiarity" (Tsivilis, Otten, & Rugg, 2001, p. 502) such as comparing familiarity strength against a given criterion. As already mentioned in the Discussion of Experiment 2, the lateral PFC including the IFG has already been proposed to serve such an evaluating downstream function in familiarity-based recognition responses (Aly et al., 2011). In Experiment 2, this region was selectively activated for reversed pairs. Therefore, it possibly has a role in relative familiarity which might be comparing the actual familiarity and the pre-experimental baseline familiarity.[1] A similar claim was made for the mid-frontal old/new effect (Stenberg et al., 2009). In addition to this parallel claim, the parallel observation of a mid-frontal old/new effect in the study by Wiegand et al. (2010) and activation of the left IFG in Experiment 2 for reversed pairs would be consistent with the left IFG being one of the neural generators of the mid-frontal old/new effect (see Bridger et al., 2012, for a discussion). This hypothesis is substantiated by the finding that activation in this region revealed by an fMRI old vs. new contrast was shown to correlate with the simultaneously recorded ERP mid-frontal old/new effect (Meyer, Hoppstädter, Bäuchl, Diener, & Flor, 2012, October).

Evaluation processes in familiarity might differ according to the type of familiarity. For example, the criterion might be determined in an absolute sense as in the notion of absolute familiarity ("Have I ever seen that item before?", MacKenzie & Donaldson, 2007). In addition, according to the discrepancy-attribution hypothesis (e.g., Whittlesea & Williams, 2001b, 2001a), familiarity evaluation might operate not on a familiarity strength signal but compare actual processing fluency with the expected processing fluency. For the same pairs in Experiment 2, there was no activation in the left IFG. Instead, same pairs specifically activated a

[1]Note, however, the alternative interpretation that the IFG activation is associated with cue specification, as argued in the Discussion of Experiment 2.

cluster in the mPFC. The mPFC was postulated to signal congruency with pre-existing knowledge (van Kesteren et al., 2012). For same pairs, this could arise from the conceptual integration of the novel units during study. Congruency might be interpreted as absolute familiarity under specific circumstances. The reduced hippocampal activation in the definition group would also be consistent with the view of van Kesteren et al. (2012, see discussion above).

In summary, although the current work cannot directly relate the ERP findings to the activation found in the fMRI study, comparison of parallel effects has turned out to be highly stimulating in considerations of how different brain regions contribute to different topographical distributions in the ERP effects. Taken together, these findings put further weight on the notion that familiarity-based responses can be determined and influenced in highly different ways in different situations. Whereas the current work emphasizes differences in downstream processes, future research might reveal commonalities and differences in the more upstream signals. For example, a common familiarity signal arising in PrC could be evaluated against a pre-experimental baseline or in an absolute sense. On the other hand, a fluency signal arising outside the MTL such as perceptual facilitation could be evaluated against the expected fluency as postulated by the discrepancy-attribution-hypothesis (e.g., Whittlesea & Williams, 2001b, 2001a).

Familiarity and Conceptual Fluency for Novel Units

Bader et al. (2010) and Wiegand et al. (2010) interpreted the reaction time decrease which they found for unitized compared to non-unitized pairs as an indication of increased conceptual fluency for the novel conceptual units. This claim was substantiated by the findings from Experiment 1 and 2 which showed faster reaction times for same than reversed pairs in the definition group but not in the sentence group. Moreover, in Experiment 3 reaction times were faster in the compound than in the unitization condition and for plausible pair-definition combinations than for implausible combinations. This is in line with increased conceptual fluency for a higher degree of unitization. In addition, the ERP data from the different studies match this interpretation by revealing reduced amplitudes of the negative deflection in the time window and topographical distribution of the N400 for pairs with a higher degree of unitization than those with a lower degree. However, the neuroimaging data are less clear with respect to this issue. Given that the enhanced mPFC activation for same pairs reflects congruency to pre-existing knowledge (van Kesteren et al., 2012), this might reflect the better integration of the novel units into semantic memory. In contrast, other brain areas usually implicated in conceptual fluency such as the left IFG, the left middle temporal gyrus (BA 21) or the anterior temporal lobes (Lau et al., 2008) did not show activity modulation specific to the novel conceptual units. The lack of activation in the PrC in Experiment 2 renders conclusions concerning a conceptual fluency component even more difficult as this region was previously associated with conceptual implicit memory (Wang et al., 2010). Nevertheless, although the relationship between familiarity for novel units and conceptual fluency cannot fully be explained by the current work, the involvement of mPFC and its possible role in semantic processing are at least tentative support for the influence of conceptual processes on recognition memory for novel conceptual units.

Contextual Influences on Familiarity

The results from the present work are in line with contextual influences on familiarity. Experiment 3, which used stimuli comparable to previous ERP studies (Rhodes & Donaldson, 2007; Bader et al., 2010; Wiegand, 2009), could not replicate the early familiarity-related old/new effects found in these studies. Otherwise being comparable, two different types of unitized associations (pre-experimental and novel) were presented intermixed in Experiment 3. As I already suggested, due to the mixed lists the most salient feature of the pairs was their pre-experimental familiarity. This feature was apparently processed in one or the other way by the participants as there were reliable differences in the ERPs between the two types: ERPs in the compound condition were more positive-going than those in the unitization condition in the N400 time window. This, however, might have rendered familiarity less salient and therefore it was not assessed. Moreover, the mixed lists induced a high variance in familiarity strength which did not covary with memory status (new pre-experimentally unitized pairs were probably more familiar than old novel units). Thus, neither the assessment of absolute nor relative familiarity was diagnostic for all pairs. This might have made participants disregard familiarity assessment completely and focus on recollection.

It is conceivable that only a part of the sub-components contributing to familiarity-based memory decisions can be influenced by contextual or strategic factors. These are probably not the components which are directly involved in computing familiarity strength as presumably the PrC. Being engaged during all kinds of tasks not related to recognition memory (Wang et al., 2010; Barense et al., 2005; K. I. Taylor et al., 2006), the PrC is less likely affected by external task-specific factors. It is rather the downstream sub-components of familiarity specific to retrieval which can be influenced. As mentioned above, the mid-frontal old/new effect was already proposed to reflect such a downstream sub-component (Tsivilis et al., 2001). In line with this proposal, task demands such as implicit vs. explicit memory tasks (Küper et al., 2012) and exlusion vs. inclusion tasks (Ecker & Zimmer, 2009) were shown to provoke the absence or presence of the early mid-frontal old/new effect (see Discussion of Experiment 3). Moreover, Tsivilis et al. (2001) found no mid-frontal old/new effect for studied items on a non-studied background. The studied items most likely were associated with an increased degree of familiarity strength compared to new items. However, although these test items had to be classified as 'old', familiarity for these items was apparently not assessed in this task whereas it was when studied items were presented on studied backgrounds. In a follow-up study, Ecker, Zimmer, Groh-Bordin, and Mecklinger (2007) replicated the findings by Tsivilis et al. (2001) but also showed that old items on a non-studied background elicited a mid-frontal old/new effect when a cue directed attention to the item and away from the background. These findings strongly support the notion that the early mid-frontal old/new effect reflects a sub-component of familiarity which can be influenced by strategic factors such as directing attention towards a stimulus (see also Mecklinger, in press, for a discussion on the functional significance of the early mid-frontal old/new effect). In a similar way, the early parietal old/new effect might reflect downstream components involved in absolute familiarity which can also be influenced by contextual factors. Due to the reasons described in the preceding paragraph, these sub-components might not have been initiated leading to the absence of the early ERP old/new effects.

The findings from Experiment 2 also include data points which might be informative regarding this issue. The reversed vs. new contrast revealed that activation in the definition group spreads further into regions previously associated with familiarity (dorsal PPC and IFG) than in the sentence group. A priori there is no reason as to why familiarity strength for the single items should be higher in the definition group than in the sentence group. However, the unavailability of recollection in the definition group might have put emphasis on the assessment of familiarity during recognition. In contrast, the non-diagnosticity of familiarity in the sentence group turned its assessment useless. Therefore, given that activation in the dorsal PPC and the left IFG was indeed associated with familiarity in Experiment 2, involvement of familiarity for the single items was moderated by study task. This is also consistent with the idea of contextual influences on familiarity.

9.2.3 Costs of Unitization

As stated by Mayes et al. (2007), if unitization is taken as an explanation for an effect on associative recognition memory, it is important to establish independent objective criteria of whether an association has actually been unitized or not. One suggestion is that unitization should not only have mnemonic benefits for the unit but also "costs of unitization" (Pilgrim, Murray, & Donaldson, 2012, p. 1672) for the constituents. As reversed pairs initially had been encoded within a unit, but the beneficial effect of the unit was disrupted by reversing the pairs, costs of unitizaition should be observable for these pairs. Thus, the following section looks more closely on the memory performance for the reversed pairs.

With respect to accuracy of the recognition judgments for same and reversed pairs, the results of Experiment 1 and 2 do not correspond. Whereas Experiment 2 revealed a selective decrement in accuracy for reversed pairs in the definition group, there was no group difference in accuracy for reversed pairs in Experiment 1. Again slightly different are the findings by Haskins et al. (2008). They also showed better performance for same than reversed pairs in the definition condition. However, accuracy for same and reversed pairs in the sentence condition was generally low which is in contrast to Experiment 2 where performance in the sentence group was relatively high. Two possible reasons for the discrepant findings were proposed in the discussion of Experiment 1. The first explanation suggested that the mixed lists (definition and sentence trials) in the Haskins et al. study induced an advantage for same pairs in the definition condition because they were the most salient test items due to their unitized meaning. While this explanation might still hold for the drop in performance for same pairs in the sentence compared to the definition condition in the Haskins et al. study, it cannot explain why accuracy for reversed pairs was selectively low in Experiment 2, but not Experiment 1 (both between-subjects designs). According to the second possible explanation mentioned in the discussion of Experiment 1, it is conceivable that presenting each word pair twice during the study phase might have boosted recollection and by this memory performance for reversed pairs. Two further findings support this explanation. First, the definition group of Experiment 1 (Wiegand et al., 2010) showed a left parietal old/new effect which was also observable for reversed pairs, albeit reduced in comparison to same pairs. Second, the lack of evidence for hippocampal involvement and the reduced engagement of other recollection-related regions, especially for reversed pairs, in the definition group of Experiment 2 suggests that recollection played a minor role when pairs were presented only once during study. Thus, only if recollection is generally engaged, it can compensate for low familiarity for reversed pairs.

The behavioral dissociation between the two different encoding conditions revealed by the reversed pairs at test is a strong indication that unitization was effective. This means that the current results show behaviorally evident costs of unitization. Pilgrim et al. (2012) found evidence for costs of unitization in the reduction of the early mid-frontal old/new effect elicited by single items which had been studied as parts of unitized pairs in contrast to items which had been studied as parts of non-unitized pairs. However, behavioral differences were not revealed in their study. As they discuss, this can probably be explained by equal levels of recollection as indexed by comparably large left parietal old/new effects. The pattern of results across the Haskins et al. (2008) study, the Wiegand et al. (2010) study, and Experiment 2 are consistent with the notion that behavioral costs as indicated by a drop in accuracy can only be observed when recollection cannot compensate for diminished familiarity.

9.2.4 Semantic vs. Episodic Memory

In Section 1.4, I argue that it is always important to be clear about whether a specific recognition memory task addresses the episodic or the semantic memory system. Further on, I point out that many of the studies investigating unitization use pre-existing associations. By this, the tasks employed in these studies are on the one hand episodic as they test if the association has occurred during a specific episode. On the other hand, the associative element of the task is actually not episodic as the association had already been established before. In contrast, the current work focused on novel units where the elements are bound during a specific episode in the study phase of the experiment. However, the definition encoding paradigm involves semantic integration during study. Also for the pictorial stimuli in Experiment 4, it cannot be ruled out that participants extracted a meaning from the scenes. Thus, the study of unitization in the way as it was accomplished here could also be seen as an instantiation of semantic learning. However, many theories assume that fast learning of novel facts is also mastered by the hippocampus and access to semantic memory becomes independent of the hippocampus only after repeated exposures (e.g., McClelland & Rogers, 2003; Moscovitch et al., 2006). Only when the encoded information has been decoupled from a specific episode, its retrieval can be accomplished by the neocortex alone (e.g., Baddeley et al., 2001; Henke, 2010). Thus, even if the definition encoding paradigm is considered as semantic learning, it is striking that it seems to be independent of the hippocampus already after one learning trial. The semantic learning view on unitization is in line with the mPFC activation signaling congruency to existing semantic knowledge (van Kesteren et al., 2012) and the role of conceptual processing in familiarity for novel units (see above).

9.3 Limitations and Outlook

While the findings described above provide convincing evidence for a dissociation between processes engaged in the retrieval of novel units and arbitrary associations, there were some unexpected null results. Thus, the post-hoc interpretation of the findings from Experiment 3 has to await further support by an independent experiment which compares the ERP old/new effects for the compound and unitization condition in mixed and pure lists. In Experiment 2, a non-optimal signal-to-noise-ratio might have been the reason for which I did not observe any perirhinal activity modulation. In future research an increase in trial number and optimization of imaging the MTL by orienting slice acquisition along the long axis of the hippocampus is advised (e.g., Giovanello et al., 2009). Furthermore, collecting additional behavioral estimates of familiarity and recollection would have been useful. Especially in Experiment 2, the mapping of brain activation to familiarity-based processing hinges on previous studies which showed a stronger reliance on familiarity after definition encoding with behavioral measures (Quamme et al., 2007; Parks & Yonelinas, 2009). However, as explained in Section 1.2.2, behavioral estimates rely to a great degree on pre-assumptions which were difficult to meet with the complex design of Experiment 2. A reduction in complexity might allow for a greater number of stimuli per condition. This would, for example, permit to model the BOLD signal according to confident judgments and would at the same time improve the signal-to-noise ratio for the fMRI signal in the MTL. At last, although Experiment 4 constitutes promising first evidence that unitization can enhance familiarity-based memory for novel object-object associations, these results need to be substantiated by other methodological approaches such as study instructions which ensure recollection for the separate condition. Moreover, in order to attribute the results ultimately to unitization, one would need to show that the scene-like encoding entails also costs of unitization.

Future research could also strengthen reference of the current work to application in special populations. For instance, unitizing or integrative encoding strategies leading to less hippocampus-dependent encoding and retrieval might help to overcome the associative memory deficit observed in older adults. Associative recognition memory is affected by aging to a greater extent than item recognition (e.g., Naveh-Benjamin, 2000). Moreover, many studies speak in favor of impaired recollection but preserved familiarity in older adults (e.g., Bastin & van der Linden, 2003; Daselaar, Fleck, Dobbins, Madden, & Cabeza, 2006; Cohn, Emrich, & Moscovitch, 2008). Interestingly, Raz et al. (2005) found greater volume loss in the hippocampus compared to the rhinal cortex. Thus, it is conceivable that deficits in binding and recollection mediated by the hippocampus are one of the key factors in explaining the associative recognition impairments in elderly (Cohn et al., 2008). Assuming that familiarity is intact in older adults and volume changes in rhinal cortex are less severe, one would expect better memory for unitized associations than non-unitized associations in older adults. However, Jäger, Mecklinger, and Kliegel (2010) found a greater age related disadvantage for unitized face pairs than for non-unitized face pairs (face stimuli as used in Jäger et al., 2006, see Section 2.3). As these unexpected findings might be explained by the special stimulus characteristics, future research has to investigate whether other forms of unitization might be effective in reducing the age related associative memory deficit.

9.4 Concluding Remarks

The results of the current thesis dissociated retrieval processes for arbitrary and newly unitized associations. Remembering arbitrary associations engages a flexible recollection process which is recruited to a lesser extent for the novel units. Moreover, different brain regions were engaged for novel units and single items. The exact functional roles of these regions, however, have still to be determined.

Moreover, whether familiarity plays a role during associative memory is probably not only dependent on the stimulus characteristics but also on contextual factors which is line with regarding at least the assessment of familiarity as not completely automatic. At last, the current work provides preliminary evidence that familiarity-based recognition is not restricted to contiguous units.

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APPENDIX A

Stimuli Used in Experiment 1 – 4

A.1 Word Pairs and Sentences Used in Experiment 1 (p. 171)

All word pairs and sentences used in the study phase are listed. Note that each single word reappeared in one recombined pair in the study phase. Recombined pairs are specified together with the old pair containing the same first word.

A.2 Word Pairs Used as New Pairs in Experiment 1 (p. 178)

All word pairs which served as new pairs in the test phase are listed.

A.3 Word Pairs, Definitions, and Sentences Used in Experiment 2 (p. 179)

All word pairs together with definitions and sentences used in the study phases for the two groups are listed. Word pairs were organized in word quadruplets (quad) so that two recombined pairs could be formed from two pairs. Recombined pairs are not listed. Both possible recombinations were used keeping the word position from the original pairs constant. Note that only one recombined pair of a quadruplet was presented to each participant but both recombined pairs were used equally often across participants.

A.4 Word Pairs and Descriptions Used in the Compound Condition in Experiment 3 (p. 187)

All word pairs of the compound condition together with the description used in the study phase are listed. Word pairs were organized in word quadruplets (quad) so that a recombined pair could be formed from two word pairs which was also a meaningful pre-existing compound word pair. Word position from the original pairs was kept constant.

A.5 Word Pairs and Definitions Used in the Unitization Condition in Experiment 3 (p. 195)

All word pairs of the unitization condition together with the definition used in the study phase are listed. Word pairs were organized in word quadruplets (quad) so that one recombined pair was formed from two word pairs. Word position from the original pairs was kept constant.

A.6 Object Pairs Used in Experiment 4 (p. 203)

Names of all object pairs are listed. Object pairs were organized in sets so that they could be recombined within the sets. Each single object appeared in the same location in the original and the recombined picture.

A.1 Word Pairs and Sentences Used in Experiment 1

original			recombined	
word 1	word 2	sentence	word 1	word 2
ALKOHOL	ZEITUNG	Über ____ konnte man viel in der ____ lesen.	ALKOHOL	GEDICHT
ARMEE	WIESE	Die ____ wurde auf der ____ gedrillt.	ARMEE	STALL
ATOM	WOHNUNG	Das ____ war in der ____ ausgestellt.	ATOM	KATZE
BAHN	HERD	Die ____ wurde mit einem ____ ausgestattet.	BAHN	TURNIER
BANK	DUSCHE	Die ____ wurde in die ____ gestellt.	BANK	KÖNIG
BEIN	ZELT	Das ____ schaute aus dem ____.	BEIN	ZIGARETTE
BENZIN	SCHULE	Das ____ konnte vor der ____ gekauft werden.	BENZIN	REIS
BERG	GRAF	Den ____ bezwang der ____ nur mühsam.	BERG	HEIZUNG
BETT	MAUER	Das ____ wurde an der ____ aufgebaut.	BETT	KIRCHE
BLITZ	GRAS	Der ____ entflammte das ____ .	BLITZ	REZEPT
BLUT	HIMMEL	Das ____ spritzte bis in den ____.	BLUT	SONNE
BOGEN	ROSE	Der ____ wurde von der ____ umschlungen.	BOGEN	HOTEL
BROT	HOTEL	Das ____ wurde in das ____ geliefert.	BROT	KETTE
BUCH	PALAST	Das ____ spielte vorwiegend in einem ____.	BUCH	SCHILD
CHOR	SENDUNG	Der ____ ist in der ____ aufgetreten.	CHOR	HÜTTE
DACH	FOTO	Das ____ wurde auf dem ____ abgebildet.	DACH	APFEL
DAMM	HEIZUNG	Auf dem ____ wurde eine ____ abgestellt.	DAMM	TAFEL
DORF	STIEFEL	Im ____ wurden gerne ____ getragen.	DORF	TONNE
EISEN	ZUNGE	Das ____ durchbohrte ihre ____.	EISEN	BILD
ERNTE	WANDERER	Die ____ erfreute den ____.	ERNTE	MÜTZE

A.1 Word Pairs and Sentences Used in Experiment 1

original			recombined	
word 1	word 2	sentence	word 1	word 2
FAUST	MÜNZE	Die ____ verfehlt die ____ nur knapp.	FAUST	WAAGE
FEDER	SÄNGER	Die ____ stand dem ____ sehr gut.	FEDER	ONKEL
FELD	DIEB	Im ____ konnte sich der ____ gut verstecken.	FELD	POKAL
FELS	GEMÄLDE	Der ____ wurde mit einem ____ verschönert.	FELS	MASCHINE
FETT	JÄGER	Das ____ wurde vom ____ entfernt.	FETT	INGENIEUR
FEUER	WURZEL	Das ____ beschädigte die ____.	FEUER	SÄNGER
FILM	REZEPT	Im ____ wurde das ____ verheimlicht.	FILM	FISCH
FINGER	BOOT	Seine ____ wurden auf dem ____ eiskalt.	FINGER	TURM
FLÜGEL	WAAGE	Der ____ wurde auf die ____ gelegt.	FLÜGEL	KELLER
FLUSS	GEBÄUDE	Der ____ war aus dem ____ gut zu sehen.	FLUSS	BAUCH
FLUT	TRAKTOR	Die ____ hielt den ____ auf.	FLUT	KISTE
GARTEN	POKAL	Im ____ wurde der ____ verliehen.	GARTEN	GENERAL
GELD	SCHIFF	Mit dem ____ wurde das ____ bezahlt.	GELD	WURZEL
GEMÜSE	BIBEL	Dieses ____ wurde bereits in der ____ erwähnt.	GEMÜSE	INSTRUMENT
GEWEHR	MÖNCH	Das ____ wurde von dem ____ begutachtet.	GEWEHR	PRÜFUNG
GEWITTER	MOTOR	Bei ____ schaltete sich der ____ ab.	GEWITTER	NONNE
GLAS	RAKETE	Das ____ wackelte beim Start der ____.	GLAS	MOTOR
GOLD	HOSE	Das ____ wurde in der ____ versteckt.	GOLD	LEHRLING
GRABEN	HERDE	Der ____ wurde von der ____ mühelos überwunden.	GRABEN	TREPPE
HAAR	KISTE	Das abgeschnittene ____ wurde in der ____ aufgehoben.	HAAR	TRAKTOR

A.1 Word Pairs and Sentences Used in Experiment 1

original			recombined	
word 1	word 2	sentence	word 1	word 2
HAFEN	BALKON	Der ____ konnte vom ____ aus gut gesehen werden.	HAFEN	BIBEL
HEBEL	TAFEL	Mit dem ____ konnte man die ____ bewegen.	HEBEL	MÜNZE
HEFT	SCHMUCK	Das ____ wurde durch den ganzen ____ verdeckt.	HEFT	RUINE
HOLZ	KIRCHE	Das ____ wurde vor der ____ abgeladen.	HOLZ	KLINIK
HORN	WELLE	Das ____ wurde von der ____ davon gespült.	HORN	MANAGER
HÜGEL	SCHILD	Der ____ wurde durch das ____ verschandelt.	HÜGEL	SCHWEIN
INSEL	KELLER	Auf der ____ gab es nur einen ____.	INSEL	WAFFE
KAFFEE	MEDAILLE	Beim ____ präsentierte sie ihre ____.	KAFFEE	RAKETE
KAMERA	HUND	Die ____ wurde vor dem ____ versteckt.	KAMERA	GRAF
KARTOFFEL	HAMMER	Die ____ wurde mit einem ____ zerteilt.	KARTOFFEL	ENTE
KINO	INGENIEUR	Im ____ amüsierte sich der ____.	KINO	SCHIFF
KLAVIER	HEMD	Das ____ verbarg hinter sich das ____.	KLAVIER	SCHMUCK
KNOCHEN	WAND	Die ____ fand man eingemauert in der ____.	KNOCHEN	SENDUNG
KOFFER	BLUME	Der ____ enthielt eine gelbe ____.	KOFFER	BRILLE
KOPF	PFLANZE	Der ____ wurde von der ____ verdeckt.	KOPF	PFEIL
KORB	PRÜFUNG	Der ____ gelang in der ____ perfekt.	KORB	MÖNCH
KUCHEN	SONNE	Der ____ wurde von der ____ aufgeweicht.	KUCHEN	SPORTLER
KUGEL	KATZE	Die ____ wurde von der ____ inspiziert.	KUGEL	ZELT
LEDER	BRIEF	Das ____ wurde in den ____ gesteckt.	LEDER	PALAST
LOHN	MASCHINE	Der ____ wurde mit der ____ gezählt.	LOHN	GEMÄLDE

A.1 Word Pairs and Sentences Used in Experiment 1

original			recombined	
word 1	word 2	sentence	word 1	word 2
MANTEL	SCHWEIN	Der ____ wurde dem ____ übergezogen.	MANTEL	REFERAT
MARKT	KÖNIG	Der ____ wurde vom ____ kontrolliert.	MARKT	HERD
MEER	TOPF	Vom ____ wurde ein ____ angespült.	MEER	ROCK
MILCH	TAXI	Die ____ wurde im ____ verschüttet.	MILCH	SESSEL
MODE	NONNE	Für ____ interessierte sich die ____ sehr.	MODE	WOHNUNG
MOND	PFEIL	Vor dem ____ war der ____ gut zu sehen.	MOND	PFLANZE
MÜNSTER	MANAGER	Im ____ saßen auch viele ____.	MÜNSTER	WELLE
MUSIK	FLIEGE	Die ____ lies die ____ verschwinden.	MUSIK	SIEDLUNG
MUTTER	REIS	Die ____ kochte oft ____.	MUTTER	MAUER
NEBEL	ENGEL	Im ____ konnte man den ____ kaum sehen.	NEBEL	ZUNGE
NETZ	WAFFE	Das ____ diente als ____.	NETZ	GARAGE
OBST	STUNDE	____ sollte nicht mehr zu später ____ gegessen werden.	OBST	TEPPICH
PARADIES	ENTE	Im ____ gibt es täglich gebratene ____.	PARADIES	HAMMER
PARK	REFERAT	Im ____ wird selten ein ____ gehalten.	PARK	ZIRKEL
PARTY	KETTE	Auf der ____ trug sie eine schöne ____.	PARTY	KAPITEL
PILOT	BÜHNE	Der ____ wurde auf der ____ perfert verkörpert.	PILOT	KLOSTER
PLAKAT	JUNGE	Das ____ riss der ____ ab.	PLAKAT	ANSTALT
PLATZ	GEDICHT	Der ____ kam in dem ____ nicht vor.	PLATZ	ZEITUNG
POST	INSTRUMENT	Mit der ____ kam auch das neue ____.	POST	FLIEGE
PROBE	KAPITEL	In der ____ wurde nur das erste ____ behandelt.	PROBE	ROSE

A.1 Word Pairs and Sentences Used in Experiment 1

original			recombined	
word 1	word 2	sentence	word 1	word 2
RADIO	ZIRKEL	Das ____ wurde mit dem ____ konstruiert.	RADIO	HIMMEL
RAHMEN	TURM	Der ____ hing ganz oben im ____.	RAHMEN	BOOT
RAUCH	APFEL	Der ____ schadete dem ____.	RAUCH	MELODIE
REGEN	TEPPICH	Der ____ ruinierte den ____.	REGEN	STUNDE
RING	STALL	Der ____ ging im ____ verloren.	RING	WIESE
ROHR	TABELLE	Das ____ wurde in der ____ verzeichnet.	ROHR	BIER
SAAL	LEITER	Im ____ war auch dessen ____ anzutreffen.	SAAL	STICH
SAND	SPIEGEL	Der ____ wurde auf dem ____ gesammelt.	SAND	JUNGE
SATTEL	FISCH	Unter dem ____ wurde der ____ zerdrückt.	SATTEL	SPIEGEL
SAUNA	BRILLE	In der ____ konnte die ____ auch getragen werden.	SAUNA	BLUME
SCHACH	HÜTTE	Mit ____ wurde es in der ____ nicht langweilig.	SCHACH	FLAGGE
SCHAF	MELODIE	Das ____ lauschte aufmerksam der ____.	SCHAF	STEIN
SCHATTEN	SPORTLER	Der ____ schützte den ____.	SCHATTEN	JÄGER
SCHNEE	KARTE	Der ____ war auf der ____ sichtbar.	SCHNEE	DAUMEN
SCHRANK	SIEDLUNG	Der ____ wurde in der ____ weiter verschenkt.	SCHRANK	RECHNUNG
SCHUH	FLAGGE	Auf den ____ war eine ____ gestickt.	SCHUH	WAND
SCHWERT	MIETE	Das ____ hatte er sich nur zur ____ beschafft.	SCHWERT	GEBÄUDE
SIEGER	RECHNUNG	Dem ____ wurde eine ____ ausgestellt.	SIEGER	MIETE
SOMMER	WANGE	Im ____ wurde ihre ____ immer ganz rot.	SOMMER	BOMBE
STADION	BAUCH	Im ____ haben viele einen dicken ____.	STADION	DIEB

A.1 Word Pairs and Sentences Used in Experiment 1

original			**recombined**	
word 1	word 2	sentence	word 1	word 2
STADT	MÜTZE	In der ____ konnte eine ____ erstanden werden.	STADT	PFERD
STAHL	BLÜTE	Aus ____ wurde eine große ____ gefertigt.	STAHL	WANDERER
STAUB	TURNIER	Der ____ beeinträchtigte das ____.	STAUB	SCHULE
STERN	SESSEL	Den ____ konnte man vom ____ aus sehen.	STERN	TAXI
STOFF	GARAGE	Der ____ wurde in der ____ gefunden.	STOFF	ENGEL
STRAND	TREPPE	Der ____ konnte über die ____ erreicht werden.	STRAND	WANGE
STRUMPF	TEAM	Der ____ wurde vom ganzen ____ gesucht.	STRUMPF	MEDAILLE
TANZ	ANSTALT	____ wurde in der ____ immer angeboten.	TANZ	TOPF
TELEFON	KLINIK	Das ____ läutete in der ____.	TELEFON	HOSE
TELLER	ROCK	Der ____ war teurer als der ____.	TELLER	GRAS
THEATER	GENERAL	Das ____ gefiel dem ____ sehr gut.	THEATER	HERDE
TISCH	PFERD	Auf dem ____ stand ein geschnitztes ____.	TISCH	BÜHNE
TRAINER	KLOSTER	Der ____ zog sich ins ____ zurück.	TRAINER	BLÜTE
TRANSPORT	BAUM	Für den ____ wurde der ____ zerlegt.	TRANSPORT	NASE
TRAUM	RUINE	Im ____ war die ____ leicht zu erklimmen.	TRAUM	BRIEF
TROMMEL	BILD	Die ____ konnte man auf dem ____ gut erkennen.	TROMMEL	HUND
VOGEL	ONKEL	Der ____ erfreute den ____ sehr.	VOGEL	HEMD
WALD	BIER	Der ____ wurde mit ____ verseucht.	WALD	TABELLE
WASSER	DAUMEN	Im ____ verletzte sie sich am ____.	WASSER	KARTE
WEIN	BOMBE	Der ____ wurde in die ____ gefüllt.	WEIN	STIEFEL

A.1 Word Pairs and Sentences Used in Experiment 1

original			recombined	
word 1	word 2	sentence	word 1	word 2
WIND	STEIN	Der ____ bewegt den ____.	WIND	FOTO
WITZ	NASE	Der ____ handelte von der großen ____.	WITZ	BAUM
WOLLE	LEHRLING	Die ____ wurde von dem ____ hergestellt.	WOLLE	TEAM
WURST	ZIGARETTE	Die ____ schmeckte besser als die ____.	WURST	DUSCHE
ZWEIG	TONNE	Der ____ wurde in die ____ geschmissen.	ZWEIG	BALKON
ZWIEBEL	STICH	Die ____ wurde sofort auf den ____ gepresst.	ZWIEBEL	LEITER

A.2 Word Pairs Used as New Pairs in Experiment 1

word 1	word 2	word 1	word 2
FIRMA	TASSE	JÜNGER	KULISSE
KRANZ	LAMPE	NACHT	FUSS
TÄTER	URLAUB	HAUFEN	REDNER
REGEL	HERZ	HALS	KNECHT
LICHT	KOCH	BUSCH	KATALOG
RICHTER	MESSE	HANDEL	OPFER
KALENDER	HALLE		
BUTTER	PISTOLE		
ARBEITER	ERDE		
FASS	AKTIE		
SILBER	SCHREIBEN		
VATER	LINIE		
OFEN	DIRIGENT		
WEIZEN	LIPPE		
ARZT	WOLKE		
MALER	PFEIFE		
FUTTER	SATTELIT		
SEKT	PLANET		
ESEL	STUFE		
REISE	HAKEN		
SCHLAF	KANTE		
KUNST	POLIZIST		
FENSTER	KIND		
TEMPEL	NAGEL		
GALERIE	PATIENT		
KAPITÄN	HUHN		
PAKET	KLINKE		
HAUT	PFARRER		
PFENNIG	DAME		
ZAHN	BODEN		
TROPFEN	STUBE		
TEST	FLASCHE		
PREIS	LEHRER		
LAGER	WESTE		
STOCK	AUTO		
KREIS	GEBIRGE		

A.3 Word Pairs, Definitions, and Sentences Used in Experiment 2

quad	word 1	word 2	definition	sentence
1	Mutter	Reis	Ein nahrhafte Mahlzeit, die stillende Frauen gerne essen	Die____ kochte oft____.
1	Absatz	Gegend	Ein Gebiet, in dem man einen sicheren Tritt hat	Der____ brach in jener____ ab.
2	Bühnen	Pilot	Ein Akrobat, der Flugkunststücke aufführt	Auf allen ____ glänzte der____.
2	Ring	Stall	Eine Unterbringung fürs Vieh, die kreisförmig ist	Der____ ging im____ verloren.
3	Tabellen	Rohr	Ein Abfluss, der in einer Übersicht verzeichnet ist	In den____ wurde jedes____ verzeichnet.
3	Agenten	Kuh	Ein Rind, das bei Spionagetätigkeiten behilflich ist	Die____ beobachteten die____.
4	Formel	Ferien	Urlaub, der perfekt vorgeplant ist	Es gibt keine____ für die perfekten____.
4	Sattel	Fisch	Ein Schuppentier, das einen Fleck auf dem Rücken hat	Unter dem____ wurde der____ zerdrückt.
5	Sätze	Konto	Die Menge, die man in einer bestimmten Zeit geredet hat	In mehreren____ füllte sich das____.
5	Kopf	Pflanzen	Grünzeug, mit dem das Haupt bedeckt werden kann	Der____ wurde von den____ verdeckt.
6	Hütten	Schach	Ein Spiel, das in Bayern sehr beliebt ist	In den____ wurde es mit____ nicht langweilig.
6	Witze	Nasen	Eine Gesichtspartie, die sich bei Scherzen verfärbt	Die____ handelten von großen____.
7	Beine	Zelt	Eine Plane, die die unteren Gliedmaßen abdeckt	Die____ schauten aus dem____.
7	Faust	Münzen	Ein Zahlungsmittel, das durch einen Hieb geprägt wurde	Die____ verfehlt die____ nur knapp.
8	Bücher	Palast	Eine Bibliothek, die besonders prächtig ist	Die____ waren in einem____ untergebracht.
8	Schatten	Sportler	Jemand, der nie im Licht trainiert	Der____ schützte den____.
9	Kino	Ingenieur	Ein Baumeister, der hauptsächlich Lichtspielhäuser konstruiert	Im____ amüsierte sich der____.
9	Schuh	Flaggen	Eine Kennzeichnung, die an Sandalen zu sehen ist	Auf den____ waren kleine____ gestickt.
10	Sessel	Stern	Ein Himmelskörper, der gut vom Sofa zu sehen ist	Vom ____ aus konnte man den____ sehen.
10	Geld	Schiff	Ein Frachter, der wertvoll beladen ist	Mit dem____ wurde das____ bezahlt.
11	Vulkane	Gesetz	Eine Vorschrift, die die Evakuierung regelt	Die ausbrechenden____ zwangen sie zu einem neuen____.

A.3 Word Pairs, Definitions, and Sentences Used in Experiment 2

quad	word 1	word 2	definition	sentence
11	Benzin	Schulen	Lehrstätten, in die alle mit dem Fahrzeug kommen	Das____ konnte an den____ gekauft werden.
12	Strümpfe	Team	Eine Mannschaft, die in Socken antritt	Der____ wurde vom ganzen____ gesucht.
12	Stunden	Obst	Früchte, die schnell vergammeln	In späten____ sollte kein____ mehr gegessen werden.
13	Fluten	Traktor	Ein Fahrzeug, das durch Überschwemmungsgebiete fahren kann	Die____ hielt den____ auf.
13	Kreis	Pfeifen	Flöten, die in der Runde umhergereicht werden	Im____ pafften sie mehrere ____.
14	Blut	Himmel	Ein Horizont, der rot gefärbt ist	Das____ spritzte bis in den____.
14	Wolle	Lehrling	Ein Auszubildender, der Strickgarn aufwickeln muss	Die____ wurde von dem____ hergestellt.
15	Kugel	Katzen	Eine Raubtierart, die eine rundliche Form hat	Die____ wurde von den____ inspiziert.
15	Wurst	Zigaretten	Glimmstängel, die nach Metzgerei riechen	Die____ schmeckte besser als die____.
16	Pfad	Ärmel	Ein Pulliteil, das lang und dünn ist	Auf dem____ fanden sie einen einzelnen____.
16	Kollegen	Fenster	Ein Ausblick, den ein Mitarbeiter genießt	Die____ putzten das____.
17	Gemüse	Bibel	Ein Nachschlagewerk, das Hobbygärtner zu Rate ziehen	Dieses____ wurde bereits in der____ erwähnt.
17	Küsse	Klage	Eine Anzeige, die eine Reihe unerlaubter Schmatzer zur Folge hat	Mehrere____ verursachten diese____.
18	Kuchen	Sonne	Die Strahlen, die einen im Café beglücken	Der____ wurde von der____ aufgeweicht.
18	Wagen	Beichte	Ein Bekenntnis, das in einem Gefährt gemacht wird	Im____ wurde die____ abgelegt.
19	Betten	Mauer	Eine Barrikade, auf der man schlafen kann	Die____ wurden an der____ aufgebaut.
19	Tisch	Pferd	Ein Dekoartikel, der wiehern kann	Auf dem____ stand ein geschnitztes____.
20	Dorf	Stiefel	Eine Fußbekleidung, die in ländlichen Gebieten getragen wird	Im____ wurden gerne____ getragen.
20	Stuhl	Faden	Ein Zwirn, der an eine Sitzgelegenheit gebunden ist	Der____ wurde vom____ umwickelt.
21	Fell	Stein	Ein Brocken, der eine weiche Oberfläche hat	Das____ wurde auf dem____ ausgebreitet.
21	Gläser	Raketen	Geschosse, die mit Drinkgefäßen beladen sind	Die____ wackelten wegen der____.
22	Elefanten	Frage	Ein Problem, das von gigantischen Ausmaßen ist	Die____ konnten die____ nicht beantworten.

A.3 Word Pairs, Definitions, and Sentences Used in Experiment 2

quad	word 1	word 2	definition	sentence
22	Provinz	Pillen	Tabletten, die gegen Langeweile helfen sollen	In der____ wurde jedem die____verschrieben.
23	Futter	Architekten	Chemiker, die Viehnahrung entwickeln	Das____ verabreichten ihm die____.
23	Mond	Pfeil	Ein angespitzter Ast, der hoch fliegen kann	Vor dem____ war der____ gut zu sehen.
24	Gitter	Studien	Ein Hochschulangebot, das unvollständig ist	Sogar hinter____ gebracht vollendete er seine____.
24	Federn	Sänger	Eine gefiederte Person, die singt	Die____ standen dem____ sehr gut.
25	Graben	Herde	Ein Rudel, das sich vorwiegend in einer Aushebung aufhält	Der____ wurde von der____ mühelos überwunden.
25	Bänke	Duschen	Nasszellen, in denen man sitzen kann	Die____ wurden in die____ gestellt.
26	Gürtel	Klub	Ein Verein, in dem alle schicke Riemen um die Hüfte tragen	____ waren in diesem____ verboten.
26	Dächer	Foto	Ein Abbild, auf dem rote Ziegel zu sehen sind	Die____ wurden auf dem____ abgebildet.
27	Hügel	Schild	Ein Verkehrshinweis, der erhöht angebracht ist	Der____ wurde durch das____ verschandelt.
27	Titel	Kinder	Nachfahren, die adelig zur Welt kommen	Mit einem____ kamen die____ zur Welt.
28	Mantel	Schweine	Masttiere, die einen schwarzen Rücken haben	Der____ wurde durch die____ verschmutzt.
28	Stoff	Garagen	Lagerhallen, in denen Textilien untergebracht werden	Der____ wurde in den____ zusammengelegt.
29	Manager	Fessel	Ein Schlinge, die einen Unternehmensführer festhält	Der____ konnte sich aus der____ befreien.
29	Busch	Ablage	Ein Versteck, das unter Sträuchern verborgen ist	Der____ überwucherte bereits die____.
30	Post	Instrument	Eine Vorrichtung, die Päckchen sortiert	Mit der____ kam auch das neue____.
30	Telefon	Klinik	Eine Werkstatt, in der Fernsprecher repariert werden	Das Telefon läutete in der Klinik.
31	Wüsten	Pudding	Ein Nachtisch, der sehr trocken ist	In den____ gab es für gewöhnlich keinen____.
31	Kamera	Hunde	Vierbeiner, die sehr fotogen sind	Für die____ interessierten sich die____ nicht.
32	Radio	Zirkel	Eine Gruppierung, die gemeinsam Hörfunk hört	Das____ wurde mit dem____ konstruiert.
32	Listen	Atom	Ein Kern, der offiziell verzeichnet ist	In den____ war das____ offiziell verzeichnet.
33	Rahmen	Turm	Eine Anhäufung, die aus Bildeinfassungen besteht	Der____ hing ganz oben im____.

A.3 Word Pairs, Definitions, and Sentences Used in Experiment 2

quad	word 1	word 2	definition	sentence
33	Zirkus	Kinn	Eine Gesichtspartie, die bunt bemalt ist	Im____ rasierte man ihm das____.
34	Stadion	Bauch	Das, was der Körper beim Fußballschauen zunimmt	Im____ haben viele einen dicken____.
34	Eisen	Zungen	Haken, die sehr stabil sind	Das____ durchbohrte die____.
35	Trainer	Kloster	Ein Ort der Einkehr, den Übungsleiter aufsuchen	Der____ zog sich ins____ zurück.
35	Nebel	Engel	Eine Kitschfigur, die in trübem Licht leuchtet	Im____ konnte man den____ kaum sehen.
36	Zwiebel	Stich	Eine Bohrung, die durch mehrere Schichten geht	Die____ wurde sofort auf den____ gepresst.
36	Staub	Turnier	Ein Wettkampf, der in der Wüste stattfindet	Der____ beeinträchtigte das____.
37	Akzent	Kandidaten	Bewerber, deren Aussprache nicht perfekt ist	Einen starken____ hatten alle____.
37	Kaffee	Medaillen	Eine Auszeichnung, die für den besten Espresso verliehen wird	Beim____ präsentierte sie ihre____.
38	Ämter	Matten	Liegen, die von Behörden bereit gestellt werden	Die____ stellten neue____ bereit.
38	Gewitter	Motor	Ein Antrieb, der selbst bei Unwetter funktioniert	Bei____ schaltete sich der____ ab.
39	Auto	Hirten	Angestellte, die einen Parkplatz bewachen	Ein günstiges____ erwarben die____.
39	Fett	Jäger	Ein Wilderer, der hinter dicken Hirschen her ist	Das____ wurde vom____ entfernt.
40	Rosen	Gabel	Ein Gerät, mit dem man Stachelgewächse pflegt	Die____ wurden mit der____ berührt.
40	Vogel	Onkel	Ein Tierliebhaber, der Geflügel züchtet	Der____ erfreute den____ sehr.
41	Ernte	Wanderer	Ein Fußgänger, der im September durch die Äcker marschiert	Die____ erfreute den____.
41	Protest	Komponist	Ein Sinfonienschöpfer, der sich auflehnt	Am____ beteiligte sich der____.
42	Flügel	Uhren	Zeitmesser, die ausklappbare Flächen haben	Der____ verdeckte eine der____ .
42	Familien	Bikini	Badebekleidung, die sich alle Kusinen teilen	In manchen____ war ein____ ausdrücklich verboten.
43	Blumen	Koffer	Ein Gepäckstück, das bunt bedruckt ist	Die____ waren im____ versteckt.
43	Gewehr	Rat	Ein Gremium, das über Schießgenehmigungen abstimmt	Das____ wurde vom____ begutachtet.
44	Hafen	Balkon	Ein Vorbau, von dem aus man die Bucht beobachten kann	Der____ konnte vom____ aus gut gesehen werden.

A.3 Word Pairs, Definitions, and Sentences Used in Experiment 2

quad	word 1	word 2	definition	sentence
44	Kapital	Ohr	Eine Hörmuschel, die mit wertvollen Klunkern dekoriert ist	Er konnte____ aus seinem guten____ schlagen.
45	Insel	Keller	Ein Höhlensystem, das auf einem Eiland zu finden ist	Auf der____ gab es nur einen____.
45	Hebel	Tafel	Ein Schreibboard, das sich mit einer Vorrichtung bewegen lässt	Mit dem____ konnte man die____ bewegen.
46	Kurven	Forscher	Ein Wissenschafter, der sich mit Rundungen befasst	Die____ wurden präzise vom____ berechnet.
46	Klavier	Hemd	Ein Kleidungsstück, das man gerne zum Musizieren anzieht	Das____ verbarg hinter sich das____.
47	Leder	Brief	Ein Schreiben, das in einem Tierhautumschlag steckt	Das____ wurde in den____ gesteckt.
47	Fliegen	Musik	Gesang, der nach Insekten klingt	Die____ wurden von der____ vertrieben.
48	Muskel	Zettel	Eine Notiz, die den Kraftzuwachs belegt	Der____ wurde auf dem____ notiert.
48	Schrank	Siedlungen	Ortschaften, in der die Behausungen sehr klein sind	Der____ wurde in den____ hergestellt.
49	Pulver	Regel	Prinzip, nach dem Material zerbröselt wird	Das____ löste sich immer nach einer bestimmten____ auf.
49	Brot	Hotel	Eine Pension, die nur spärliche Kost anbietet	Das____ wurde in das____ geliefert.
50	Sand	Spiegel	Eine Stelle auf einer Düne, die reflektiert	Der____ wurde auf dem____ gesammelt.
50	Berg	Graf	Ein Adliger, der weit oben wohnt	Den____ bezwang der____ nur mühsam.
51	Teil	Held	Ein Kämpfer, der nicht immer siegt	Zu einem großen____ war der____ bereits verbittert.
51	Mode	Nonne	Eine Ordensschwester, die schick gekleidet ist	Für____ interessierte sich die____ sehr.
52	Transport	Baum	Ein Stamm, den man zur Beförderung flussabwärts schickt	Für den____ wurde der____ zerlegt.
52	Löwen	Knoten	Ein verfilztes Büschel, das in einer Mähne zu finden ist	Die____ zerrten am____.
53	Paradies	Enten	Geflügel, das ein besonders schönes Gefieder hat	Im____ gibt es täglich gebratene____.
53	Bilder	Trommel	Ein Schlagzeug, das farbig bedruckt ist	Die____ zeigten alle eine____.
54	Spitzen	Organ	Ein Körperteil, das Höchstleistungen erbringt	Bis in die____ beanspruchte er sein gebeuteltes____.
54	Zebra	Finale	Ein Lauf, bei dem die Sprinter schwarz-weiß gekleidet sind	Das____ schaffte es bis ins____.
55	Bahn	Herd	Eine Kochgelegenheit, die man mitunter in einem Wagon findet	Die____ wurde mit einem____ ausgestattet.

A.3 Word Pairs, Definitions, and Sentences Used in Experiment 2

quad	word 1	word 2	definition	sentence
55	Knochen	Wand	Ein Wall, der aus Gebeinen aufgeschichtet ist	Den____ fand man eingemauert in der____.
56	Damm	Heizungen	Eine Vorrichtung, die das Gefrieren des Erdwalls verhindert	Auf dem____ wurden einige____ abgestellt.
56	Feind	Wolken	Eine Schmutzaufwirbelung, die der Gegner hinterlässt	Der____ schien in den____ zu verschwinden.
57	Feuer	Wurzel	Ein dunkles Kraut, das scharf schmeckt	Das____ beschädigte die____.
57	Schaf	Melodie	Klänge, die den Lauten junger Lämmer ähneln	Das____ lauschte aufmerksam der____.
58	Referate	Park	Eine Grünanlage, in der Vorträge gehalten werden	____ werden selten im____ gehalten.
58	Finger	Boot	Ein Dampfer, der auf kleinen Gewässern fährt	Sein kleiner____ wurde auf dem____ eiskalt.
59	Fluss	Gebäude	Eine Unterkunft, die Kanuwanderer nutzen	Der____ war aus dem____ gut zu sehen.
59	Prinzen	Zahl	Eine Ziffer, die einem Glück bringt	Die schlauen____ vergötterten jegliche____.
60	Haar	Kisten	Die Schachteln, in der beim Friseur die Reste landen	Abgeschnittenes____ wurde in den____ aufgehoben.
60	Hals	Wochen	Ein Rabattaktion, die Nackenmassagen anbietet	Der____ schmerzte in diesen____.
61	Hafer	Tanten	Weibliche Verwandte, die gesund frühstücken	Ausschließlich von____ ernährten sich die____.
61	Milch	Taxi	Ein Bringservice, der von einem Bauerngut kommt	Die____ wurde im____ verschüttet.
62	Juli	Gewerbe	Eine Tätigkeit, die einem im Sommer ein Einkommen beschert	Im____ ging er wieder seinem____ nach.
62	Wunder	Dielen	Flure, in denen man verzaubert wird	Ein____ wurde in den____ vollbracht.
63	Wellen	Horn	Ein Geweih, das nicht besonders gerade ist	Leichte____ waren an dem____ zu erkennen.
63	Hefte	Schmuck	Ein Accessoire, das einer Zeitschrift beigelegt ist	Die____ wurden durch den ganzen____ verdeckt.
64	Kartoffel	Hammer	Ein Werkzeug, mit dem Erdäpfel zerkleinert werden	Die____ wurde mit einem____ zerteilt.
64	Dokument	Stufen	Übergange, die in einem Schriftstück zu finden sind	Das____ wurde auf den____ gefunden.
65	Korb	Prüfungen	Ein Examen, das zeigt, ob man Behälter flechten kann	Der____ gelang nach den____ perfekt.
65	Opern	Rand	Die Sitze, die ganz hinten in einem Schauspielhaus sind	In____ sitzt er immer ganz am____.
66	Lohn	Maschinen	Automaten, die wöchentlich das Gehalt auszahlen	Der____ wurde mittels ____ gezählt.

A.3 Word Pairs, Definitions, and Sentences Used in Experiment 2

quad	word 1	word 2	definition	sentence
66	Film	Rezept	Die Beschreibung, wie man einen guten Streifen dreht	Im____ wurde das____ verheimlicht.
67	Tomaten	Papst	Ein Oberpriester, der sich vegetarisch ernährt	Die____ schmeckten dem____ außerordentlich gut.
67	Sauna	Brillen	Sehhilfen, die auch bei großer Hitze von Nutzen sind	In der____ konnten die____ auch getragen werden.
68	Netz	Waffen	Verknüpfte Seile, mit denen man angreifen kann	Im____ landeten auch alte____.
68	Theater	General	Ein Darsteller, der gerne militärische Rollen übernimmt	Das____ gefiel dem____ sehr gut.
69	Spuren	Augen	Der Blick, der in die richtige Richtung weist	Er verfolgte die____ mit seinen____.
69	Teller	Rock	Ein Kleidungsstück, das einen runden Saum hat	Der____ war teurer als der____.
70	Täter	Element	Ein Aspekt, der einen Verbrecher überführt	Der____ war ganz in seinem____.
70	Platz	Gedicht	Lyrik, die auf öffentlichen Flächen vorgetragen wird	Der____ kam in dem____ nicht vor.
71	Text	Damen	Ältere Frauen, die viele Schriftstücke kennen	Der____ handelte von bezaubernden____.
71	Stürze	Liga	Ein Wettbewerb, in dem spektakulär gefallen wird	Tiefe____ in der____ waren abzusehen.
72	Triumph	Kamm	Ein Frisörwerkzeug, das nach Erfolgen benutzt wird	Den____ belohnte sie sich mit einem neuen____.
72	Blitz	Gras	Halme, die schnell wachsen	Der____ entflammte das____.
73	Tonnen	Zweig	Ein Ast, der schon weggeworfen wurde	In den____ wurde kein____ gefunden.
73	Dichter	Nummern	Showeinlagen, die bei einem Poesiewettbewerb gezeigt werden	Der____ trug mehrere____ hintereinander vor.
74	Tanz	Anstalten	Spezielle Einrichtungen, in denen man Ballett lernen kann	____ wurde in allen____ angeboten.
74	Felder	Dieb	Ein Räuber, der Getreide stielt	Die____ ließ der____ schnell hinter sich.
75	Felsen	Gemälde	Eine Darstellung, die auf Gestein gezeichnet ist	Die____ wurden mit einem____ verschönert.
75	Garten	Pokal	Die Trophäe, die für die schönste Grünanlage vergeben wird	Im____ wurde der____ verliehen.
76	Probe	Kapitel	Einige Textpassagen, die vorab veröffentlicht werden	In der____ wurde das erste____ behandelt.
76	Hosen	Gold	Garn, das Kleidungsstücke veredelt	An den____ schimmert ein wenig____ .
77	Kirchen	Holz	Material, mit dem man Gotteshäuser ausstattet	Die____ wurden aus____ gebaut.

A.3 Word Pairs, Definitions, and Sentences Used in Experiment 2

quad	word 1	word 2	definition	sentence
77	Stadt	Mützen	Kappen, die außerordentlich mondän sind	In der____ konnten____ erstanden werden.
78	Wein	Bomben	Ein Sprengsatz, der die Umstehenden betrunken macht	Der____ wurde in die____ gefüllt.
78	Treppen	Strand	Eine Bucht, die über mehrere Terrassen verläuft	Die____ führten direkt zum____.
79	Markt	Chor	Händler, die gemeinsam Waren anpreisen	Auf dem____ trat ein____ auf.
79	Karten	Schnee	Eine Naturerscheinung, die im Atlas verzeichnet ist	Die____ zeigten grötenteils den____.
80	Regen	Teppich	Ein Bodenbelag, der Nässe aushält	Der____ ruinierte den____.
80	Leiter	Saal	Räumlichkeiten, die für Führungskräfte vorgesehen sind	Der ____ war auch im____ anzutreffen.

A.4 Word Pairs and Descriptions Used in the Compound Condition in Experiment 3

	original			recombined	
quad	word 1	word 2	description	word 1	word 2
1	Abend	Mahl	Ein Handlung, die im Gottesdienst durchgeführt wird	Abend	Kurs
1	Computer	Kurs	Eine Veranstaltung, in der man PC-Programme kennenlernt		
2	Abfall	Produkt	Ein Rest, der weggeschmissen wird	Abfall	Eimer
2	Blech	Eimer	Ein Kübel, der leicht und stabil ist		
3	Akt	Modell	Eine Person, die abgezeichnet wird	Akt	Zeichnung
3	Strich	Zeichnung	Eine Graphik, die nur aus Konturen besteht		
4	Alarm	Anlage	Eine Vorrichtung, die Einbrecher aufschreckt	Alarm	Signal
4	Ton	Signal	Ein Hinweis, der hörbar ist		
5	Arm	Reif	Ein Schmuckstück, das ums Handgelenk getragen wird	Arm	Band
5	Stirn	Band	Eine Textile, die den Schopf aus dem Gesicht hält		
6	Bar	Hocker	Eine Sitzgelegenheit, die am Tresen steht	Bar	Mann
6	Zimmer	Mann	Ein Handwerker, der umherzieht		
7	Bass	Gitarre	Ein Utensil, das bei einer Rockband nicht fehlen darf	Bass	Stimme
7	Mädchen	Stimme	Laute, die mit hoher Frequenz gesprochen werden		
8	Beton	Bunker	Eine Höhle, die einen sicher schützt	Beton	Bau
8	Kanal	Bau	Eine Konstruktion, die unter der Erde stattfindet		
9	Biologie	Professor	Ein Dozent, der Lebenswissenschaften lehrt	Biologie	Test
9	Intelligenz	Test	Ein Verfahren, das die Klugheit misst		
10	Box	Schlag	Ein Hieb, den man in der Arena platziert	Box	Kampf
10	Stier	Kampf	Ein Wettstreit, in dem ein Bulle teilnimmt		

A.4 Word Pairs and Descriptions Used in the Compound Condition in Experiment 3

	original			recombined	
quad	word 1	word 2	description	word 1	word 2
11	Braut	Strauß	Ein Gebinde, das für eine Hochzeit gebraucht wird	Braut	Kleid
11	Ball	Kleid	Eine Robe, die bei einer Tanzveranstaltung getragen wird		
12	Burg	Fräulein	Eine Jungfer, die in einer Festung residiert	Burg	Hof
12	Gast	Hof	Ein Lokal, in dem man übernachten kann		
13	Büro	Möbel	Einrichtungsgegenstände, die am Arbeitsplatz zu finden sind	Büro	Lampe
13	Flur	Lampe	Ein Licht, das im Eingangsbereich hängt		
14	Chemie	Experiment	Ein Versuch, bei dem Substanzen gemischt werden	Chemie	Labor
14	Medizin	Labor	Ein Abteil, in dem klinische Versuche gemacht werden		
15	Dollar	Bündel	Ein Stapel, der wertvoll ist	Dollar	Symbol
15	Euro	Symbol	Eine Veranschaulichung, die für unsere Währung steht		
16	Draht	Zaun	Ein Geflecht, das eine Grenze zieht	Draht	Zange
16	Loch	Zange	Ein Apparat, mit dem gestanzt werden kann		
17	Ehe	Leute	Ein Paar, das verheiratet ist	Ehe	Berater
17	Steuer	Berater	Ein Dienstleister, der in Finanzfragen hilft		
18	Eis	Bär	Ein Raubtier, das in der Arktis lebt	Eis	Becher
18	Würfel	Becher	Ein Gefäß, mit dem man zocken kann		
19	Fest	Torte	Feingebäck, das für einen besonderen Anlass ist	Fest	Essen
19	Mensa	Essen	Ein Speise, die es an der Uni gibt		
20	Brand	Geruch	Gestank, der nach einer Entzündung aufkommt	Brand	Schaden
20	Frost	Schaden	Ein Defekt, der wegen Kälte entstanden ist		

A.4 Word Pairs and Descriptions Used in the Compound Condition in Experiment 3

	original			**recombined**	
quad	word 1	word 2	description	word 1	word 2
21	Frucht	Mark	Weiche Masse, die aus Beeren gewonnen wird	Frucht	Presse
21	Druck	Presse	Ein Apparat, mit dem Schriftstücke hergestellt werden		
22	Funk	Gerät	Eine Vorrichtung, mit der man in Verbindung bleiben kann	Funk	Uhr
22	Spiel	Uhr	Ein Zeitmesser, der auch unterhaltsam ist		
23	Fuß	Boden	Eine Fläche, die innen zu finden ist	Fuß	Bad
23	Schlamm	Bad	Eine Wanne, die mit Matsch gefüllt ist		
24	Gas	Flamme	Eine Lichterscheinung, die beim Verbrennen entstehen kann	Gas	Flasche
24	Schnaps	Flasche	Ein Behälter, der mit Hochprozentigem gefüllt ist		
25	Gefängnis	Strafe	Eine Maßnahme, bei der ein Mensch eingesperrt wird	Gefängnis	Wärter
25	Zoo	Wärter	Ein Pfleger, der sich um Affen und Tiger kümmert		
26	Gemeinde	Pfarrer	Ein Pastor, der für eine Kommune zuständig ist	Gemeinde	Versammlung
26	Partei	Versammlung	Ein Treffen, das Gleichgesinnte zusammenbringt		
27	Gepäck	Träger	Eine Konstruktion, mit der man Lasten transportiert	Gepäck	Fach
27	Wäsche	Fach	Ein Regal, in dem auch Bettlaken liegen		
28	Gewinn	Los	Ein Beleg, der in der Lotterie einen Wert hat	Gewinn	Rätsel
28	Wort	Rätsel	Eine Denkaufgabe, die Buchstaben enthält		
29	Gewürz	Nelke	Eine Zutat, die gerne in Saucen gemischt wird	Gewürz	Gurke
29	Essig	Gurke	Ein Erdgewächs, das sauer eingelegt ist		
30	Grund	Gebühr	Ein Beitrag, der häufig zu zahlen ist	Grund	Stück
30	Fund	Stück	Eine Sache, die wieder aufgetaucht ist		

A.4 Word Pairs and Descriptions Used in the Compound Condition in Experiment 3

	original			recombined	
quad	word 1	word 2	description	word 1	word 2
31	Haus	Arzt	Ein Doktor, der regelmäßig konsultiert wird	Haus	Tier
31	Beute	Tier	Ein Lebewesen, das erlegt wird		
32	Haut	Farbe	Der Teint, der einem angeboren ist	Haut	Falte
32	Speck	Falte	Gewebe, das an der Hüfte zu viel ist		
33	Herz	Operation	Ein Eingriff, der sehr kompliziert ist	Herz	Schmerz
33	Zahn	Schmerz	Ein Leiden, das man im Kiefer merkt		
34	Industrie	Betrieb	Eine Firma, die produziert	Industrie	Ofen
34	Kohle	Ofen	Eine Heizung, die mit Brennstoff betrieben wird		
35	Internet	Portal	Ein Informationsbereich, den man online findet	Internet	Händler
35	Schrott	Händler	Ein Kaufmann, der alte Ware weiter verkauft		
36	Jagd	Schloss	Eine Residenz, die Zugang zum Wildgehege hat	Jagd	Schein
36	Flug	Schein	Eine Lizenz, die das Führen von Luftfahrzeugen erlaubt		
37	Kakao	Getränk	Ein Trunk, der nach Schokolade schmeckt	Kakao	Geschmack
37	Vanille	Geschmack	Ein Aroma, das von einer braunen Schote stammt		
38	Kern	Physik	Eine Wissenschaft, die sich mit der Materie beschäftigt	Kern	Kraft
38	Körper	Kraft	Die Stärke, die wir mit eigenem Leib aufbringen		
39	Klima	Wechsel	Eine Veränderung, die einen in ein andere Witterung bringt	Klima	Zone
39	Ost	Zone	Das Gebiet, das von der Sowjet-Union besetzt wurde		
40	Knie	Kehle	Die Beuge, die oberhalb des Unterschenkels sitzt	Knie	Scheibe
40	Ziel	Scheibe	Ein Bereich, der getroffen werden soll		

A.4 Word Pairs and Descriptions Used in the Compound Condition in Experiment 3

	original			**recombined**	
quad	word 1	word 2	description	word 1	word 2
41	Kunst	Museum	Räumlichkeiten, die Malerei und Skulpturen zeigen	Kunst	Werk
41	Meister	Werk	Ein Stück, das perfekt gelungen ist		
42	Laden	Kasse	Vorrichtung, an der Kunden bezahlen müssen	Laden	Besitzer
42	Restaurant	Besitz	Eine Person, die eine Gaststätte betreibt		
43	Luft	Schlange	Eine Dekoration, die an Fasching verwendet wird	Luft	Krieg
43	Bürger	Krieg	Übergriffe, die innerhalb eines Staates stattfinden		
44	Mathematik	Aufgabe	Ein Problem, das mit Rechnen gelöst wird	Mathematik	Note
44	Zeugnis	Note	Eine Zensur, die man am Schuljahresende bekommt		
45	Metall	Knopf	Ein Verschluss, der stabil ist	Metall	Platte
45	Silber	Platte	Ein Tablett, das zu edlen Anlässen verwendet wird		
46	Mord	Prozess	Ein Verfahren, bei dem es um ein Tötungsdelikt geht	Mord	Opfer
46	Terror	Opfer	Ein Mensch, der in einen Anschlag verwickelt wurde		
47	Müll	Grube	Eine Vertiefung, in der Unrat gelagert wird	Müll	Haufen
47	Kies	Haufen	Eine Ansammlung, die als Baustoff verwendet wird		
48	Nagel	Lack	Eine Schicht, die bei der Maniküre aufgetragen wird	Nagel	Studio
48	Fitness	Studio	Ein Center, in dem man sich körperlich betüchtigt		
49	Pflege	Personal	Angestellte, die sich um die Kranken kümmern	Pflege	Sohn
49	Enkel	Sohn	Ein Junge, der zur Verwandschaft zweiten Grades zählt		
50	Polizei	Revier	Eine Stelle, in der Ordnungshüter stationiert sind	Polizei	Uniform
50	Militär	Uniform	Eine Montur, die im Heer getragen wird		

A.4 Word Pairs and Descriptions Used in the Compound Condition in Experiment 3

	original			recombined	
quad	word 1	word 2	description	word 1	word 2
51	Radieschen	Beet	Anbaufläche, in der Knollengewächse wachsen	Radieschen	Salat
51	Blatt	Salat	Ein Gewächs, das grün und saftig ist		
52	Reise	Pass	Ein Ausweis, mit dem man Grenzen überqueren kann	Reise	Tasche
52	Brust	Tasche	Ein Eingriff, der innen im Jackett zu finden ist		
53	Salz	Fass	Ein Behälter, in dem ein weiße Kochzutat gelagert wird	Salz	Korn
53	Pfeffer	Korn	Ein Krümel, der sehr scharf ist		
54	Samt	Decke	Ein Überwurf, der aus einem glänzenden Stoff ist	Samt	Kissen
54	Nadel	Kissen	Ein Polster, in dem Nähzubehör steckt		
55	Schädel	Basis	Die Gebeine, die das Gehirn von unten stützen	Schädel	Verletzung
55	Schulter	Verletzung	Eine Behinderung, die das Tragen erschwert		
56	Schlaf	Lied	Strophen, die beim Einschlummern helfen sollen	Schlaf	Anzug
56	Schutz	Anzug	Ein Overall, der einen abschirmt		
57	Schlüssel	Bund	Ein Anhänger, mit dem man durch viele Eingänge kommt	Schlüssel	Haken
57	Karabiner	Haken	Eine Vorrichtung, in die man ein Seil einhängen kann		
58	Schnitt	Punkt	Stelle, an der sich Linien treffen	Schnitt	Wunde
58	Schuss	Wunde	Eine Blessur, die durch ein Geschoss entstanden ist		
59	Schüler	Sprecher	Ein Vertreter, der von den Klassensprechern gewählt wird	Schüler	Kalender
59	Termin	Kalender	Eine Agenda, in der Verabredungen vermerkt werden		
60	See	Ufer	Ein Landstrich, der ein Binnengewässer einsäumt	See	Sack
60	Plastik	Sack	Ein Beutel, der aus Kunststoff besteht		

A.4 Word Pairs and Descriptions Used in the Compound Condition in Experiment 3

	original			**recombined**	
quad	word 1	word 2	description	word 1	word 2
61	Sport	Kleidung	Klamotten, die man bei körperlicher Betüchtigung trägt	Sport	Klub
61	Nacht	Klub	Eine Lokalität, in der getanzt und getrunken wird		
62	Sprung	Brett	Ein Sportgerät, von dem man ins Becken hüpft	Sprung	Stab
62	Staffel	Stab	Ein Stock, der beim Mannschaftslauf übergeben wird		
63	Stroh	Ballen	Trockene Getreidehalme, die aufgerollt sind	Stroh	Hut
63	Filz	Hut	Eine Kappe, die aus einem Faserstoff gefertigt ist		
64	Strom	Leitung	Ein Kabel, in dem Elektrizität fließt	Strom	Quelle
64	Lärm	Quelle	Ein Zentrum, in dem Krach entsteht		
65	Tat	Motiv	Der Umstand, der zu einem Verbrechen antreibt	Tat	Ort
65	Heimat	Ort	Die Region, in der man aufgewachsen ist		
66	Tee	Tasse	Ein Gefäß, aus dem man heiße Flüssigkeiten trinkt	Tee	Löffel
66	Dessert	Löffel	Ein Essbesteck, mit dem man Nachtisch ist		
67	Tennis	Lehrer	Ein Übungsleiter, der eine Ballsportart unterrichtet	Tennis	Halle
67	Messe	Halle	Ein Areal, auf dem Ausstellungen stattfinden		
68	Tür	Schlitz	Ein Spalt, der am Eingang offen steht	Tür	Griff
68	Revolver	Griff	Der Schaft, der an einer Pistole zu finden ist		
69	Unfall	Zeuge	Ein Beobachter, der einen Zusammenstoß sieht	Unfall	Station
69	Wetter	Station	Eine Einrichtung, in der die Witterung beobachtet wird		
70	Wahl	Kabine	Ein Vorrichtung, in der man sein Kreuzchen macht	Wahl	Plakat
70	Reklame	Plakat	Ein Aushang, der für etwas wirbt		

A.4 Word Pairs and Descriptions Used in the Compound Condition in Experiment 3

	original			recombined	
quad	word 1	word 2	description	word 1	word 2
71	Welt	Konzern	Ein Unternehmen, das global agiert	Welt	Raum
71	Konferenz	Raum	Ein Bereich, in dem Besprechungen abgehalten werden		
72	Zeichen	Block	Ein Utensil, das zum Malen verwendet wird	Zeichen	Sprache
72	Schrift	Sprache	Eine Redeweise, die sehr formell ist		
73	Zinn	Krug	Eine Kanne, die schwer und rustikal ist	Zinn	Soldat
73	Marine	Soldat	Ein Streitkräfteangehöriger, der auf Kreuzern dient		
74	China	Tourist	Ein Ausländer, der durch Asien reist	China	Kohl
74	Winter	Kohl	Eine Krautart, die bei Kälte geerntet wird		
75	Grab	Kreuz	Ein Denkmahl, das auf einem Friedhof zu finden ist	Grab	Kammer
75	Schatz	Kammer	Eine Höhle, in der Juwelen liegen		
76	Handy	Tastatur	Oberfläche, mit der man ein Kommunikationsgerät bedient	Handy	Vertrag
76	Profi	Vertrag	Eine Vereinbarung, die einen Fußballer an ein Team bindet		
77	Jazz	Kapelle	Eine Band, die Dixieland und Swing spielt	Jazz	Konzert
77	Orchester	Konzert	Eine Aufführung, die von einem Ensemble dargeboten wird		
78	Märchen	Erzählung	Eine Geschichte, in der Fantasiegestalten vorkommen	Märchen	Figur
78	Roman	Figur	Eine Person, die in einer Erzählung vorkommt		
79	Rad	Tour	Ein Ausflug, der mit dem Drahtesel gemacht wird	Rad	Weg
79	Tor	Weg	Eine Straße, die zur Einfahrt führt		
80	Tempel	Diener	Ein Gehilfe, der in einer heiligen Stätte waltet	Tempel	Säule
80	Ruf	Säule	Ein Apparat, an dem Notfälle mitgeteilt werden können		

A.5 Word Pairs and Definitions Used in the Unitization Condition in Experiment 3

	original			recombined	
quad	word 1	word 2	description	word 1	word 2
1	Pilot	Bühne	Ein Schauplatz, auf dem neue Stücke probeweise aufgeführt werden	Pilot	Stall
1	Ring	Stall	Eine Unterbringung fürs Vieh, die kreisförmig ist		
2	Kuh	Agent	Ein Vermittler, der im Rinderhandel tätig ist	Kuh	Tabelle
2	Rohr	Tabelle	Eine Übersicht, in der sich alle Abflüsse finden lassen		
3	Formel	Urlaub	Ein Schuppentier, das einen Fleck auf dem Rücken hat	Formel	Fisch
3	Sattel	Fisch	Ferien, die perfekt vorgeplant sind		
4	Satz	Konto	Die Menge, die man in einer bestimmten Zeit geredet hat	Satz	Pflanze
4	Kopf	Pflanze	Grünzeug, mit dem das Haupt bedeckt werden kann		
5	Schach	Hütte	Eine Gesichtspartie, die sich bei Scherzen verfärbt	Schach	Nase
5	Witz	Nase	Eine Unterkunft, in der viel gespielt wird		
6	Bein	Zelt	Ein Zahlungsmittel, das durch einen Hieb geprägt wurde	Bein	Münze
6	Faust	Münze	Eine Plane, die die unteren Gliedmaßen abdeckt		
7	Buch	Palast	Eine Bibliothek, die besonders prächtig ist	Buch	Sportler
7	Schatten	Sportler	Jemand, der nie im Licht trainiert		
8	Kino	Ingenieur	Ein Baumeister, der hauptsächlich Lichtspielhäuser konstruiert	Kino	Flagge
8	Schuh	Flagge	Ein Kennzeichnung, die an Sandalen zu sehen ist		
9	Geld	Schiff	Ein Frachter, der wertvoll beladen ist	Geld	Sessel
9	Stern	Sessel	Ein Sofa, auf dem man gut die Gestirne beobachten kann		
10	Vulkan	Gesetz	Eine Vorschrift, die die Evakuierung regelt	Vulkan	Schule
10	Benzin	Schule	Eine Lehrstätte, in die alle mit dem Fahrzeug kommen		

A.5 Word Pairs and Definitions Used in the Unitization Condition in Experiment 3

	original			recombined	
quad	word 1	word 2	description	word 1	word 2
11	Strumpf	Team	Eine Mannschaft, die in Socken antritt	Strumpf	Stunde
11	Obst	Stunde	Die Tageszeit, zu der Bananen am besten schmecken		
12	Traum	Ruine	Bruchstücke, die von einem schläfrigen Erlebnisübrig bleiben	Traum	Bier
12	Wald	Bier	Ein Getränk, das nach Tanne schmeckt		
13	Flut	Traktor	Ein Fahrzeug, das durch Überschwemmungsgebiete fahren kann	Flut	Beichte
13	Wagen	Beichte	Ein Bekenntnis, das in einem Gefährt gemacht wird		
14	Blut	Himmel	Ein Horizont, der rot gefärbt ist	Blut	Lehrling
14	Wolle	Lehrling	Ein Auszubildender, der Strickgarn aufwickeln muss		
15	Kugel	Katze	Ein Raubtier, das eine rundliche Form hat	Kugel	Zigarette
15	Wurst	Zigarette	Ein Glimmstängel, der nach Metzgerei riecht		
16	Ärmel	Verbot	Eine Vorschrift, die lange Pullis untersagt	Ärmel	Kollege
16	Fenster	Kollege	Ein Mitarbeiter, der einen Schreibtisch mit viel Licht hat		
17	Gemüse	Bibel	Ein Nachschlagewerk, das Hobbygärtner zu Rate ziehen	Gemüse	Klage
17	Kuss	Klage	Eine Anzeige, die ein unerlaubter Schmatzer zur Folge hat		
18	Kuchen	Sonne	Die Strahlen, die einen im Café beglücken	Kuchen	Pfeife
18	Kreis	Pfeife	Eine Flöte, die in der Runde umhergereicht wird		
19	Bett	Mauer	Eine Barrikade, hinter der man schlafen kann	Bett	Pferd
19	Tisch	Pferd	Ein Dekoartikel, der wiehern kann		
20	Dorf	Stiefel	Eine Fußbekleidung, die in ländlichen Gebieten getragen wird	Dorf	Faden
20	Stuhl	Faden	Ein Zwirn, der an eine Sitzgelegenheit gebunden ist		

A.5 Word Pairs and Definitions Used in the Unitization Condition in Experiment 3

	original			recombined	
quad	word 1	word 2	description	word 1	word 2
21	Fell	Stein	Ein Brocken, der eine weiche Oberfläche hat	Fell	Rakete
21	Glas	Rakete	Ein Geschoss, das durchsichtig ist		
22	Fett	Jäger	Ein Wilderer, der hinter dicken Hirschen her ist	Fett	Wiese
22	Armee	Wiese	Ein Rasen, auf dem die Streitkräfte üben		
23	Frage	Elefant	Ein Dickhäuter, der Antworten gibt	Frage	Pille
23	Provinz	Pille	Eine Tablette, die gegen Langeweile helfen soll		
24	Futter	Architekt	Ein Chemiker, der Viehnahrung entwickelt	Futter	Pfeil
24	Mond	Pfeil	Ein angespitzter Ast, der hoch fliegen kann		
25	Gitter	Studium	Ein Hochschulangebot, das unvollständig ist	Gitter	Sänger
25	Feder	Sänger	Eine leichte Person, die singt		
26	Graben	Herde	Ein Rudel, das sich vorwiegend in einer Aushebung aufhält	Graben	Dusche
26	Bank	Dusche	Eine Brause, in der man sitzen kann		
27	Gürtel	Verein	Ein Klub, in dem alle schicke Riemen um die Hüfte tragen	Gürtel	Foto
27	Dach	Foto	Ein Abbild, auf dem rote Ziegel zu sehen sind		
28	Hügel	Schild	Ein Verkehrshinweis, der erhöht angebracht ist	Hügel	Kind
28	Titel	Kind	Ein Baby, das adelig zur Welt kommt		
29	Mantel	Schwein	Ein Masttier, das einen schwarzen Rücken hat	Mantel	Garage
29	Stoff	Garage	Ein Verschlag, in dem Textilien gelagert werden		
30	Münster	Manager	Ein Verwalter, der für eine große Kathedrale zuständig ist	Münster	Ablage
30	Busch	Ablage	Ein Versteck, das unter Sträuchern verborgen ist		

A.5 Word Pairs and Definitions Used in the Unitization Condition in Experiment 3

	original			recombined	
quad	word 1	word 2	description	word 1	word 2
31	Pudding	Wüste	Ein karges Gebiet, das einen wackeligen Untergrund hat	Pudding	Hund
31	Kamera	Hund	Ein Vierbeiner, der sehr fotogen ist		
32	Radio	Zirkel	Eine Gruppierung, die gemeinsam Hörfunk hört	Radio	Wohnung
32	Atom	Wohnung	Eine Behausung, die sehr klein ist		
33	Rahmen	Turm	Eine Anhäufung, die aus Bildeinfassungen besteht	Rahmen	Kinn
33	Zirkus	Kinn	Eine Gesichtspartie, die bunt bemalt ist		
34	Stadion	Bauch	Das, was der Körper beim Fußballschauen zunimmt	Stadion	Zunge
34	Eisen	Zunge	Eine Lasche, die sehr stabil ist		
35	Trainer	Kloster	Ein Ort der Einkehr, denÜbungsleiter aufsuchen	Trainer	Engel
35	Nebel	Engel	Eine Kitschfigur, die in trübem Licht leuchtet		
36	Wein	Bombe	Ein Sprengsatz, der die Umstehenden betrunken macht	Wein	Miete
36	Schwert	Miete	Die Leihgebühr, die für ein Kriegswerkzeug bezahlt werden muss		
37	Zwiebel	Stich	Eine Bohrung, die durch mehrere Schichten geht	Zwiebel	Turnier
37	Staub	Turnier	Ein Wettkampf, der in der Wüste stattfindet		
38	Akzent	Kandidat	Ein Bewerber, dessen Aussprache nicht perfekt ist	Akzent	Medaille
38	Kaffee	Medaille	Eine Auszeichnung, die für den besten Espresso verliehen wird		
39	Amt	Matte	Eine Liege, die die Behörden bereitstellen	Amt	Motor
39	Gewitter	Motor	Ein Antrieb, der selbst bei Unwetter funktioniert		
40	Auto	Hirte	Ein Angestellter, der einen Parkplatz bewacht	Auto	Blüte
40	Stahl	Blüte	Ein Deko-Gewächs, das extrem bruchfest ist		

A.5 Word Pairs and Definitions Used in the Unitization Condition in Experiment 3

	original			**recombined**	
quad	word 1	word 2	description	word 1	word 2
41	Bogen	Rose	Ein stacheliges Gewächs, das über einer Pforte wächst	Bogen	Onkel
41	Vogel	Onkel	Ein Tierliebhaber, der Geflügel züchtet		
42	Ernte	Wanderer	Ein Fußgänger, der im September durch die Äcker marschiert	Ernte	Komponist
42	Protest	Komponist	Ein Sinfonienschöpfer, der sich auflehnt		
43	Fessel	Rat	Ein Gremium, das Handschellen einsetzt	Fessel	Kamm
43	Abwehr	Kamm	Ein Frisierapparat, mit dem man Ungeziefer loswird		
44	Flügel	Waage	Ein Messapparat, der ausklappbare Flächen hat	Flügel	Familie
44	Bikini	Familie	Eine Sippe, die immerzu im Freibad ist		
45	Gewehr	Mönch	Ein Glaubensbruder, der schwer bewaffnet ist	Gewehr	Blume
45	Koffer	Blume	Grünzeug, das ein Gepäckstück schmückt		
46	Hafen	Balkon	Eine Terrasse, von der aus man die Bucht beobachten kann	Hafen	Ohr
46	Kapital	Ohr	Eine Hörmuschel, die mit wertvollen Klunkern dekoriert ist		
47	Insel	Keller	Ein Höhlensystem, das auf einem Eiland zu finden ist	Insel	Tafel
47	Hebel	Tafel	Ein Schreibboard, das sich mit einer Vorrichtung bewegen lässt		
48	Klavier	Hemd	Ein Kleidungsstück, das man gerne zum Musizieren anzieht	Klavier	Kurve
48	Forscher	Kurve	Umweg, den ein Wissenschaftler macht		
49	Musik	Fliege	Ein Schlips, den man beim Singen trägt	Musik	Brief
49	Leder	Brief	Ein Schreiben, das in einem Tierhautumschlag steckt		
50	Muskel	Zettel	Eine Notiz, die den Kraftzuwachs belegt	Muskel	Siedlung
50	Schrank	Siedlung	Eine Kolonie, in der die Behausungen sehr klein sind		

A.5 Word Pairs and Definitions Used in the Unitization Condition in Experiment 3

	original			**recombined**	
quad	word 1	word 2	description	word 1	word 2
51	Pfad	Taufe	Die Gelegenheit, bei der eine Route zum ersten Mal gegangen wird	Pfad	Zeitung
51	Alkohol	Zeitung	Eine Fachzeitschrift, in der es um Spirituosen geht		
52	Pulver	Regel	Prinzip, nach dem Material zerbröselt wird	Pulver	Hotel
52	Brot	Hotel	Eine Pension, die nur spärliche Kost anbietet		
53	Sand	Spiegel	Eine Stelle auf einer Düne, die reflektiert	Sand	Graf
53	Berg	Graf	Ein Adliger, der weit oben wohnt		
54	Teil	Held	Ein Kämpfer, der nicht immer siegt	Teil	Nonne
54	Mode	Nonne	Eine Ordensschwester, die schick gekleidet ist		
55	Transport	Baum	Ein Stamm, den man zur Beförderung flussabwärts schickt	Transport	Löwe
55	Knoten	Löwe	Ein Steppenbewohner, der eine verfilzte Mähne hat		
56	Trommel	Bild	Eine Darstellung, die sich vorne auf einem Schlagzeug befindet	Trommel	Ente
56	Paradies	Ente	Geflügel, das ein besonders schönes Gefieder hat		
57	Zebra	Finale	Ein Lauf, bei dem die Sprinter schwarz-weiß gekleidet sind	Zebra	Spitze
57	Organ	Spitze	Die Höchstleistung, die vom Körper erbracht werden kann		
58	Bahn	Herd	Eine Kochgelegenheit, die man mitunter in einem Wagon findet	Bahn	Daumen
58	Wasser	Daumen	Ein Körperteil, mit dem man die Badetemperatur prüft		
59	Damm	Heizung	Eine Vorrichtung, die das Gefrieren des Erdwalls verhindert	Damm	Wolke
59	Feind	Wolke	Eine Schmutzaufwirbelung, die der Gegner hinterlässt		
60	Feuer	Wurzel	Ein dunkles Kraut, das scharf schmeckt	Feuer	Melodie
60	Schaf	Melodie	Klänge, die den Lauten junger Lämmer ähneln		

A.5 Word Pairs and Definitions Used in the Unitization Condition in Experiment 3

	original			recombined	
quad	word 1	word 2	description	word 1	word 2
61	Finger	Boot	Ein Dampfer, der auf kleinen Gewässern fährt	Finger	Referat
61	Park	Referat	Ein Vortrag, der im Freien gehalten wird		
62	Fluss	Gebäude	Eine Unterkunft, die Kanuwanderer nutzen	Fluss	Zahl
62	Prinz	Zahl	Eine Ziffer, die einem Glück bringt		
63	Haar	Kiste	Eine Schachtel, in der beim Friseur die Reste landen	Haar	Diele
63	Wunder	Diele	Ein Flur, in dem man verzaubert wird		
64	Hafer	Tante	Eine Verwandte, die gesund frühstückt	Hafer	Taxi
64	Milch	Taxi	Ein Bringservice, der von einem Bauerngut kommt		
65	Hals	Woche	Ein Rabattaktion, die Nackenmassagen anbietet	Hals	Gewerbe
65	Juli	Gewerbe	Eine Tätigkeit, die einem im Sommer ein Einkommen beschert		
66	Heft	Schmuck	Ein Accessoire, das einer Zeitschrift beigelegt ist	Heft	Welle
66	Horn	Welle	Ein Krümmung, die ein Geweih erleiden kann		
67	Kartoffel	Hammer	Ein Werkzeug, mit dem Erdäpfel zerkleinert werden	Kartoffel	Stufe
67	Dokument	Stufe	Ein Übergang, der in einem Schriftstück zu finden ist		
68	Korb	Prüfung	Ein Examen, das zeigt, ob man Behälter flechten kann	Korb	Oper
68	Rand	Oper	Ein Bühnenstück, das nur von wenigen gesehen wird		
69	Lohn	Maschine	Ein Automat, der das Gehalt auszahlt	Lohn	Rezept
69	Film	Rezept	Die Beschreibung, wie man einen guten Streifen dreht		
70	Messer	Papst	Ein Oberpriester, der gern mit scharfen Klingen hantiert	Messer	Brille
70	Sauna	Brille	Eine Sehhilfe, die auch bei großer Hitze von Nutzen ist		

A.5 Word Pairs and Definitions Used in the Unitization Condition in Experiment 3

	original			recombined	
quad	word 1	word 2	description	word 1	word 2
71	Rauch	Apfel	Eine Delikatesse, die im Qualm reift	Rauch	Wange
71	Sommer	Wange	Eine Backe, die schön gerötet ist		
72	Spur	Auge	Der Blick, der in die richtige Richtung weist	Spur	Rock
72	Teller	Rock	Ein Kleidungsstück, das einen runden Saum hat		
73	Täter	Element	Ein Aspekt, der einen Verbrecherüberführt	Täter	Gedicht
73	Platz	Gedicht	Lyrik, die auf öffentlichen Flächen vorgetragen wird		
74	Text	Dame	Eine Frau, die viele Schriftstücke kennt	Text	Liga
74	Sturz	Liga	Ein Wettbewerb, in dem spektakulär gefallen wird		
75	Triumph	Nahrung	Verpflegung, die zum Erfolg beiträgt	Triumph	Gras
75	Blitz	Gras	Halme, die schnell wachsen		
76	Zweig	Tonne	Ein Behälter, in den kleine Äste geworfen werden	Zweig	Nummer
76	Dichter	Nummer	Ein Auftritt, der bei einem Poesiewettbewerb gezeigt wird		
77	Akademie	Volk	Eine Nation, die sehr gebildet ist	Akademie	Kette
77	Party	Kette	Eine Reihe von Feiern, die man nacheinander feiert		
78	Chor	Sendung	Eine Übertragung, die singende Menschen zeigt	Chor	Rechnung
78	Sieger	Rechnung	Ein Scheck, den der Gewinner erhält		
79	Tanz	Anstalt	Eine Einrichtung, in der man Ballett lernen kann	Tanz	Dieb
79	Feld	Dieb	Ein Räuber, der Getreide stielt		
80	Fels	Gemälde	Eine Darstellung, die auf Gestein gezeichnet ist	Fels	Pokal
80	Garten	Pokal	Die Trophäe, die für die schönste Grünanlage vergeben wird		

A.6 Object Pairs Used in Experiment 4

	original		recombined	
set	object 1	object 2	object 1	object 2
1	donkey	can	donkey	mushroom
1	dinosaur	dime	dinosaur	can
1	zebra	mushroom	zebra	dime
2	witch	telescope	witch	wolf
2	airplane	wolf	airplane	telescope
3	hat	lama	hat	camel
3	comb	camel	comb	lama
3	shower	snowman	shower	skeleton
3	skipping-rope	skeleton	skipping-rope	snowman
4	baseball cap	goat	baseball cap	gorilla
4	flathat	gorilla	flathat	mouse
4	crown	mouse	crown	goat
5	tomato	cup	tomato	trophy
5	onion	trophy	onion	cup
6	skunk	skateboard	skunk	sled
6	beaver	sled	beaver	skateboard
7	monkey	motorcycle	monkey	saddle
7	rabbit	saddle	rabbit	motorcycle
8	seahorse	hanger	seahorse	medal
8	hook	medal	hook	hanger
9	sheep	rug	sheep	ladder
9	fox	ladder	fox	rug
9	watering-can	dustbin	watering-can	boot
9	teapot	boot	teapot	bowl
9	ball	bowl	ball	dustbin
10	razor	bricks	razor	ashtray
10	toothbrush	ashtray	toothbrush	bricks
11	fishing-rod	cherry	fishing-rod	strawberry
11	ostrich	strawberry	ostrich	cherry
12	pliers	pitcher	pliers	vase
12	drill	vase	drill	pitcher
13	hammer	peanut	hammer	towel
13	ax	carrot	ax	peanut
13	saw	envelope	saw	carrot
13	pitchfork	towel	pitchfork	envelope
14	egg	wagon	egg	ironing board
14	candle	ironing board	candle	wagon

A.6 Object Pairs Used in Experiment 4

	original		recombined	
set	object 1	object 2	object 1	object 2
15	radio	barrel	radio	stool
15	glas	stool	glas	barrel
16	telephone	dresser	telephone	chest
16	wine glass	chest	wine glass	dresser
17	umbrella	cat	umbrella	cowboy
17	light bulb	cowboy	light bulb	cat
18	nail	jar	nail	piggybank
18	ring	piggybank	ring	jar
19	bottle	bag	bottle	basket
19	water-tap	basket	water-tap	bag
20	boat	road	boat	railroad
20	canoo	railroad	canoo	road
21	clock	coat	clock	wheelbarrow
21	apple	wheelbarrow	apple	coat
22	banana	hammock	banana	fire
22	feather	fire	feather	hammock
23	tape	plate	tape	desk
23	iron	desk	iron	plate
24	plaster	turtle	plaster	frog
24	balloon	frog	balloon	turtle
25	cigarette	hippo	cigarette	snail
25	whistle	snail	whistle	hippo
26	trumpet	tiger	trumpet	sphinx
26	harmonica	giraffe	harmonica	tiger
26	bugle	sphinx	bugle	giraffe
27	doll	drum	doll	steering wheel
27	panda	steering wheel	panda	drum
28	wreath	cannon	wreath	gun
28	tire	gun	tire	cannon
29	screwdriver	ear	screwdriver	lock
29	corkscrew	lock	corkscrew	ear
30	squirrel	broom	squirrel	piano
30	penguin	piano	penguin	broom

A.6 Object Pairs Used in Experiment 4

	original		**recombined**	
set	object 1	object 2	object 1	object 2
31	screw	pencil-sharpener	screw	button
31	tweezers	watermelon	tweezers	pencil-sharpener
31	arrow	button	arrow	spiderweb
31	torch light	spiderweb	torch light	watermelon
32	tennis racket	hamburger	tennis racket	sandwich
32	scissors	sandwich	scissors	hamburger
33	fan	dog	fan	duck
33	tv	duck	tv	dog
34	plug	lips	plug	knob
34	syringe	knob	syringe	lips