Brain and Cognition 83 (2013) 93–103

Contents lists available at SciVerse ScienceDirect

Brain and Cognition

journal homepage: www.elsevier.com/locate/b&c

Semantic relations differentially impact associative recognition memory: Electrophysiological evidence

Olga Kriukova *, Emma Bridger, Axel Mecklinger

Experimental Neuropsychology Unit, Department of Psychology, Saarland University, Saarbrücken, Germany

ARTICLE INFO

Article history:
Accepted 19 July 2013

Keywords:
Associative recognition
Event-related potentials
Recollection
Familiarity
Semantic relations

ABSTRACT

Though associative recognition memory is thought to rely primarily on recollection, recent research indicates that familiarity might also make a substantial contribution when to-be-learned items are integrated into a coherent structure by means of an existing semantic relation. It remains unclear how different types of semantic relations, such as categorical (e.g., *dancer–singer*) and thematic (e.g., *dancer–stage*) relations might affect associative recognition, however. Using event-related potentials (ERPs), we addressed this question by manipulating the type of semantic link between paired words in an associative recognition memory experiment. An early midfrontal old/new effect, typically linked to familiarity, was observed across the relation types. In contrast, a robust left parietal old/new effect was found in the categorical condition only, suggesting a clear contribution of recollection to associative recognition for this kind of pairs. One interpretation of this pattern is that familiarity was sufficiently diagnostic for associative recognition of thematic relations, which could result from the integrative nature of the thematic relatedness compared to the similarity-based nature of categorical pairs. The present study suggests that the extent to which recollection and familiarity are involved in associative recognition is at least in part determined by the properties of semantic relations between the paired associates.

1. Introduction

Human memory enables us to store and access general world knowledge, such as concepts, facts and interrelations, collectively referred to as semantic memory (Hodges & Graham, 2001; Squire & Zola, 1998). While semantic memory is a store of crystallized, common knowledge, episodic memory refers to the storage of personalized information associated with a specific spatiotemporal context that can be "re-experienced" during retrieval (Tulving, 1985, 2002). According to dual-process models of episodic recognition memory (Aggleton & Brown, 2006; Eichenbaum, Yonelinas, & Ranganath, 2007; Jacoby, 1991; Mandler, 1980; Rugg & Yonelinas, 2003; Yonelinas, 2002; Yonelinas, Aly, Wang, & Koen, 2010) recognizing that an item or an event was previously experienced can be mediated by two qualitatively distinct processes, termed familiarity and recollection. Fast-acting and relatively automatic familiarity is based on a subjective feeling of prior encounter that can vary in strength but does not bring to mind specific details of a study episode (Mandler, 1980; Mecklinger, 2006; Rugg & Yonelinas, 2003; Yonelinas, 2002). In contrast, recollection provides access to detailed information about the prior occurrence of an item and its associated episodic context (Rugg & Curran, 2007; Rugg & Yonelinas, 2003; Woodruff, Hayama, & Rugg, 2006; Yonelinas, 2002). Episodic memory is known to benefit from the active access to and elaboration of semantic memory representations (Craik, 2002; Craik & Lockhart, 1972), for example, making use of semantic relational information enhances the recognition of associations between elements of an event (Badham, Estes, & Maylor, 2012; Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003; Patterson, Light, Van Ocker, & Olfman, 2009). Here, we consider the way in which semantic memory impacts upon episodic recognition and, specifically, how particular semantic relationships might differentially interact with familiarity and recollection.

Event-related potentials (ERPs) provide a useful tool for investigating processes involved in episodic recognition. In old/new recognition tests, correctly recognized old items typically elicit more positive-going waveforms than correctly rejected new items between 300 and 600 ms post-stimulus over frontal electrodes and 500–800 ms over parietal electrodes. These early midfrontal and left parietal old/new effects are generally taken to reflect the contributions of familiarity and recollection, respectively, to episodic recognition memory (Curran, 2000; Rugg & Curran, 2007; for an alternative perspective see Voss & Paller, 2009). A common way to probe associative recognition is to ask participants to study a list of paired associates and at test, to present them with another list for which they have to discriminate between the pairs previously seen in the same combination (old), studied in different

* Corresponding author. Address: Experimental Neuropsychology Unit, Department of Psychology, Saarland University, Saarbrücken 66123, Germany. Fax: +49 681 302 6516.

E-mail address: olga.kriukova@googlemail.com (O. Kriukova).

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http://dx.doi.org/10.1016/j.bandc.2013.07.006

combinations (rearranged), and completely new pairs. By including rearranged pairs at test, such experiments ensure that participants identify old pairs by retrieving a relational link and not by simply recognizing individual items as old (Hockley & Consoli, 1999). Whilst early ERP studies provide evidence for a critical contribution of recollection in associative recognition tasks of this type (Donaldson & Rugg, 1998), there now exist a number of reports in the literature demonstrating that familiarity may also play an important role when associations emphasize semantic processing (Opitz & Cornell, 2006; Rhodes & Donaldson, 2008). In one such investigation, Greve, van Rossum, and Donaldson (2007) reported that semantic relatedness of to-be-learned associations promotes familiarity-based recognition. Participants first studied paired associates that either shared a categorical membership (e.g., *rabbit–mouse*) or were unrelated (e.g., *hair–radio*). These were preceded by a category label which was related to the word pairs in the semantic condition and unrelated in the non-semantic one. Subsequently participants were given a recognition test during which old and rearranged/new word pairs, cued by category labels, had to be discriminated. As is typical of associative recognition experiments, the results revealed a robust left parietal old/new effect in both conditions, in line with a comparable contribution of recollection to associative recognition of categorical and unrelated pairs. In contrast, the early midfrontal old/new effect was larger for categorically-related than for unrelated word pairs leading Greve et al. to conclude that the presence of a coherent semantic structure boosts familiarity-based associative recognition. Though plausible, it may be worth replicating this outcome under standard associative recognition conditions which circumvent double priming (once by a category label, the second time by a within-pair) that could have also contributed to the enhanced early midfrontal old/new effect in the categorical condition.

It is also possible that different types of semantic relations differentially modulate episodic memory. This prospect was examined here, by focusing on categorical relations, such as those employed by Greve and colleagues, and thematic relations which have been shown to provide a distinct mechanism for organizing conceptual knowledge. Categorical relatedness, one of the major organizing principles of conceptual structure, refers to the way in which items that are conceptually or perceptually similar are often organized under the same category, e.g., *cherry–plum*, whilst distinct items fall into different categories (Estes, Golonka, & Jones, 2011; Hampton, 2000; Lin & Murphy, 2001; Markman and Wisniewski, 1997; Rosch, 1975). The defining characteristic of categorical relations is feature similarity; categorically related concepts of the same ontological level typically share many dimensions on which they can be compared (Wisniewski & Bassok, 1999) and are characterized by high semantic feature overlap as shown in a number of similarity-rating studies (Estes & Jones, 2009; Perraudin & Mounoud, 2009; Wisniewsky and Bassok, 1999). In contrast, high feature overlap is not a characteristic of thematic relations, which refer to relationships that emerge between entities participating in the same event or scene (Estes et al., 2011; Lin & Murphy, 2001). Experiments on categorization (Greenfield & Scott, 1986; Lin & Murphy, 2001; Saalbach & Imai, 2007) and priming (Estes & Jones, 2009; Hare, Jones, Thomson, Kelly, & McRae, 2009; Moss, Ostrin, Tyler, & Marslen-Wilson, 1995; Sass, Sachs, Krach, & Kircher, 2009) have shown that thematic relations provide an important alternative basis for structuring human conceptual knowledge. Rather than grouping concepts according to their internal features, thematic relations group concepts according to the complementary roles that they play in a common external scenario (Estes et al., 2011; Lin & Murphy, 2001; Murphy, 2001). For example, these might be functional (e.g., *knife–bread*), temporal (e.g., *morning – coffee*), spatial (e.g., *ceiling – lamp*), containment (e.g., *milk–jar*) or causal (e.g., *joke – laughter*) (Estes et al., 2011; Lin & Murphy, 2001; Sachs et al., 2011; Wisniewski & Bassok, 1999). Estes and Jones (2009) demonstrated that whenever two concepts which fit a common theme are encountered, they are rapidly integrated, as evidenced by facilitated processing of a target word in a priming paradigm (for a similar finding see Badham et al., 2012). Thematic relations between items might emerge spontaneously from the affordances of the current situation. For instance, a *lipstick* and *note*, typically unrelated to one another, are functionally related in a situation where it is necessary to leave a note and, in the absence of a pen, lipstick might be the only available means of writing (Estes et al., 2011). The focus of the present work however is on conventional thematic relations – salient relations with well-established representations in semantic memory (Estes et al., 2011; Lin & Murphy, 2001), e.g., *pen–note*. The conventionalization of relations occurs as interacting items frequently reappear in the same real-world situation (Estes et al., 2011), such as pen and note repeatedly co-occur in an office-scene. Through multiple exposures to the same contextual item combination, items become tightly associated and subsequently integrated into coherent representations (Opitz & Cornell, 2006) with prototypical context serving as "the 'glue' that binds objects in coherent scenes" (Bar, 2004, p. 617).

The integrative nature of thematic relations makes them interesting from the standpoint of studies on associative recognition, which show that recognition of several items encoded as a unified meaningful structure can be supported by familiarity (Giovanello, Keane, & Verfaellie, 2006; Quamme, Yonelinas, & Norman, 2007; Rhodes & Donaldson, 2007). Most studies on unitization have used existing or newly formed lexical compounds whose constituent parts have lost their individual representations and fused into a single meaningful structure. Unlike compound words of this kind, thematically related word pairs preserve their individual meanings and yet form a joint representation or theme. This characteristic of thematic relation appears to impact recognition memory. Some evidence in support of this comes from an ERP study by Opitz and Cornell (2006). In that study, participants learned quadruplets of words where three words were pre-experimentally related via frequent contextual co-occurrence, e.g., *desert*, *camel*, *oasis* alongside a fourth unrelated filler word. Participants studied the quadruplets while making contextual fit judgments which encouraged them to think about a common theme, or while making size judgments which promoted non-semantic processing. Subsequently, participants were given a single item recognition test. The results revealed that only words studied in the context of the thematic fit task elicited an early midfrontal old/new effect. These data thus suggest that processing relations in terms of themes can foster familiarity-based recognition of single items.

The goal of the present experiment was to explore whether categorical and thematic relations differentially modulate the episodic processes involved in associative recognition. As the experiment was designed to investigate the impact of semantic relations between individual concepts per se and not the impact of unitization, the study task was designed to deliberately discourage unitization (compound-formation) strategies by requiring participants to perform a separate item imagery task on sequentially presented words. Afterwards, participants performed an associative recognition test in which they had to discriminate between old, rearranged, and new pairs. By manipulating the kind of semantic relation between the paired concepts and recording ERPs during the test phase, we aimed to obtain electrophysiological signatures of familiarity and recollection during the associative recognition of the two relation types. The greater capacity of thematic relations to support holistic processing was expected to lead to a greater contribution from familiarity-based recognition, reflected in a larger early midfrontal old/new effect relative to that for categorical pairs. The predictions concerning the behavior of the left-parietal

Table 1
Illustration of item construction in Experiment 1.

Set	Quadruplet	Main word 1	Main word 2	Categorical	Thematic	Unrelated	Unrelated
1	1	Dancer	Actor	Singer	Stage	Strawberry	Orchard
1	2	Cherry	Plum	Strawberry	Orchard	Singer	Stage
2	1	Ring	Bracelet	Necklace	Present	Meadow	Sun
2	2	Desert	Prairie	Meadow	Sun	Necklace	Present

old/new effect were more open. One possibility is that the parietal effect does not differ according to relation type, given the importance of recollection for associative recognition in general (Donaldson & Rugg, 1998; Greve et al., 2007). Another possibility follows from recent results showing that successful completion of an associative recognition task is possible in the absence of a significant parietal old/new effect, the ERP correlate of recollection (Bader, Mecklinger, Hoppstädter, & Meyer, 2010; Jäger, Mecklinger, & Kipp, 2006). For example, Bader et al. (2010) reported that associative recognition of items encoded as unitized representations was associated with a reliable early old/new effect, only. Although the use of unitization strategies was discouraged in the present study, perception of related pairs as joint themes could possibly attenuate the contribution of recollection to associative recognition in the thematic condition resulting in a smaller left parietal effect compared to the categorical condition.

2. Materials and methods

2.1. Participants

Eighteen participants, none of whom were involved in the pre-experimental rating of materials, took part in the experiment for course credit or payment. All participants gave their informed consent. The experiment was approved by the local ethics committee at Saarland University. Each participant completed two study-test sessions with a gap of approximately one week between the sessions. The data from two participants were discarded due to chance performance at test for old or new items in one of the conditions of interest and subsequently an insufficient number of artifact-free trials for ERP analysis. The remaining 16 participants (11 female) were on average 23 years old (age range 19–26 years old). All participants were native German speakers, right-handed and had normal or corrected to normal vision.

2.2. Materials

The current experiment required a sufficient number of categorically and thematically related pairs, as well as unrelated filler pairs to divert attention away from the main relations of interest. 520 common concrete German nouns were initially selected and arranged into 130 sets each containing four words (Table 1). Every quadruplet was organized around two primary categorically-related words (e.g. *dancer*, *actor*) which came from categories such as vegetables, fruits, clothing, professions, natural phenomena, tools, food, beverages, animals, insects, furniture. It was possible to combine each of the primary words in the quadruplet with either a third word ("*singer*") to form two further categorical pairs, or with a fourth word ("*stage*"), resulting in two thematically related pairs. Various types of thematic relations were employed (functional, spatial, causal, etc.). Thus, each quadruplet could produce two categorical and two thematic pairs. Quadruplets were then organized into 65 paired sets and two primary words from one quadruplet were paired with word 3 and word 4 from the second quadruplet to generate four unrelated pairs (see Table 1). In sum, the materials permitted the construction of 1040 word pairs (520 semantically related and 520 unrelated).

To ensure that word pairs conveyed the intended relationships, a questionnaire pretest was conducted in which participants were asked to verify the type of relation for each word pair ("Are the two words: categorically related – thematically related – unrelated"; for a similar rating approach see Estes & Jones, 2009; Perraudin & Mounoud, 2009; Wisniewski and Bassok, 1999). In addition to relation-type, every word pair was evaluated on a four-point scale on three additional criteria[1]. By completing a statement with one of the given options, participants had to judge a pair of concepts on how unitized they are ("The two words can be very well/well/hardly/not bound into a single concept"), how semantically related ("The two words share a lot/many/few/no semantic features") or how tightly associated the concepts are ("The two words are very well/well/hardly/not associated with each other"). Prior to filling in the questionnaire participants went through a set of instructions defining the principal concepts. Semantic features were defined as common properties that two concepts have, e.g., *village–town*. Words were considered unitized when the second word could be attached to the first word leading to a formation of a compound, e.g., *apple–basket*. Words were considered associated if the first word would immediately bring to mind the second word, e.g., *hockey–ice*. There were two versions of the questionnaire, both of which included a relation-verification question and a unitization question. Version 1 asked participants to evaluate each word pair on semantic relatedness, whilst version 2 queried the associative strength of word pairs. Half of the participants received the questionnaire in version 1, and the other half received version 2. All participants who took part in the pre-experimental rating ($n = 171$) were psychology students at Saarland University, native German speakers, and were on average 22 years old (range 18–36).

Word pairs were selected on the basis of the relation-verification question in order to ensure that the constructed word-pairs represented the designated relations. Data from four participants were discarded from analysis because their total number of misclassified responses to the relation verification question deviated more than 2 *SD* from the mean number of misclassifications. Forty-five sets were selected (out of the total 65) in which all word pairs received a high inter-rater agreement in terms of existing relations. For these items, the inter-rater agreement for relation verification question was 90.3% for categorical relation, 90.1% for thematic and 95.6% for unrelated. Associative strength, semantic relatedness and unitization were compared for the selected categorical, thematic and unrelated pairs and are presented in Table 2 along with word-length and frequency information. As revealed by questionnaire-ratings, both categorical and thematic word pairs were judged more related, more associated and more unitizable than unrelated word pairs, all p-values < .01. As expected, categorical pairs were judged more related than thematic, p-values < .001, suggesting that items belonging to the same category share more semantic feature overlap. Thematic pairs in turn were perceived

[1] Though there are databases that provide measures of semantic relatedness and associative strength of word pairs for German, they remain rather limited and did not allow us to obtain information for all of the constructed word pairs. Translating the materials and obtaining the required measures from English databases was also problematic because multiple translations are usually possible for each word. Pre-experimental ratings of materials were therefore collected, which enabled us to obtain semantic relatedness, associative strength and unitizability ratings for all the word pairs in their original language.

Table 2
Stimulus properties.

	Semantic relatedness	Associative strength	Unitization	Frequency	Length
Categorical	1.84 (.03)	2.21 (.04)	3.29 (.03)	1.02 (.06)	6.26 (.20)
Thematic	3.36 (.02)	2.11 (.04)	2.45 (.05)	1.31 (.06)	6.44 (.23)
Unrelated	3.91 (.01)	3.87 (.01)	3.84 (.01)	1.18 (.04)	6.35 (.15)

Mean semantic relatedness, associative strength and unitization (standard error) revealed by pre-experimental ratings, logarithmic word frequency per million obtained from Celex and mean word length (standard error). Lower numbers for semantic relatedness, associative strength and unitization reflect higher ratings.

as more unitizable and more associated than categorical, both *p*-values < .05.

All 45 sets selected for the experiment were pseudo-randomly assigned to 9 item groups. The assignment of item groups to relation (categorical, thematic, unrelated filler) and type (old, recombined, new) conditions was counterbalanced. In each experimental session, a study list comprised 40 categorical, 40 thematic and 40 unrelated pairs. A test list comprised 60 old, 60 rearranged and 60 new pairs (20 pairs of each relation in each item type category).

2.3. Design and procedure

Stimuli were presented on a 19″ monitor (Courier New, font size 22) in black on a white background using E-prime. A response box (RB Series by Cedrus) was used as an input device. During study, participants memorized pairs of words that were either categorically/thematically-related, or unrelated. In order to prevent spontaneous compound formation, all items were presented sequentially and an item imagery task was employed, in which participants were required to make judgments concerning the clarity of the mental images for each item. Each trial began with a fixation cross presented for 1000 ms, followed by a blank screen for 250 ms and then the first word appeared for 400 ms. A blank screen (1000 ms) followed during which participants had to mentally visualize the named object. After this a fixation cross (250 ms) appeared, followed by a blank screen (250 ms). The second word then appeared (400 ms) for which participants were also instructed to create a mental image (during the presentation of a blank screen, 1000 ms). At the end of each trial, a question mark appeared on the screen prompting participants to compare the two mental images and indicate by a button press whether the first or second image was clearer, or whether both were equally clear (maximum duration 2000 ms). The inter-trial interval was 100 ms. The study phase was subdivided into 4 blocks, separated by self-paced breaks. After the study phase, a visual search distracter task was performed for 5 min to prevent rehearsal of the materials.

The test phase immediately followed the distracter task. Each test trial started with a 1000 ms fixation cross, followed by a 500 ms blank screen, after which a word pair was presented for 800 ms. Words were presented on the same level, one to the left and one to right of center. A response display followed this (max. duration 2200 ms) during which participants were to identify the word pair as either old, rearranged or new by pressing one of the three respective response buttons. After providing their response, participants had to rate their response confidence (max. duration 1500 ms) as "sure" or "unsure". A 100 ms inter-trial interval followed. The test phase consisted of 4 blocks separated by self-paced breaks.

Categorical, thematic and unrelated pairs were pseudo-randomly intermixed in both the study and test sessions, such that word pairs in the same relation-condition could not appear on more than two subsequent trials. The same words were used in both sessions but their pairs differed across sessions, e.g., pairs that were assigned to categorical condition at session 1 appeared in the thematic or unrelated condition at session 2. It was necessary to test participants twice in order to generate a sufficient number of trials for ERP analysis whilst ensuring all stimulus materials were sufficiently well controlled.

2.4. Data acquisition

EEG was recorded from 58 silver/silver-chloride electrodes embedded in an elastic cap (Easycap) according to the extended International 10–20 system (American Electroencephalographic Society, 1994). Two other electrodes were placed at each mastoid. EOG was recorded from four electrodes located above and below the right eye and on the outer canthi of both eyes. Data were acquired with an amplifier bandpass from DC to 70 Hz and digitalized at a sampling rate of 500 Hz with a resolution of 16-bit. Electrode impedances were kept below 5 kΩ. EEG was recorded using a left-mastoid reference but all EEG channels were offline re-referenced to an average of the signal recorded at both mastoids. Further offline processing included filtering with a low-pass set to 30 Hz and splitting the data into individual epochs from 100 ms pre-stimulus to 1000 ms post-stimulus. Epochs containing eye artifacts were corrected using the procedure suggested by Gratton, Coles, and Donchin (1983), while trials containing other artifacts (whenever standard deviation in a 200 ms time interval exceeded 30 μV in either Cz or any of EOG channels) were rejected. After eliminating trials containing artifacts, mean averages were computed for the conditions of interest for each participant at all recording sites. The mean number of trials for old and new pairs was 25 (range 11–32) and 28 (range 18–36) in the categorical condition, and 21 (range 10–32) and 27 (15–34) in the thematic condition.

2.5. Data analysis

Repeated measures analyses of variance (ANOVAs) were employed for the inferential statistics. For all ANOVAs, *F*-values associated with more than 1 degree of freedom in the nominator have been corrected for sphericity violations with Greenhouse–Geisser procedure. Uncorrected degrees of freedom and corrected *p*-values are reported. Probability values of the subsidiary *t*-tests were adjusted using Holm–Bonferroni correction (Holm, 1979). For all analyses, the significance level was set to .05.

The principal reason recombined pairs were included in the test phase was to ensure that participants relied on associative recognition and could not make their responses solely on the basis of item memory. In line with previous reports of this paradigm (Bader et al., 2010; Greve et al., 2007; Rhodes & Donaldson, 2007; Wiegand, Bader, & Mecklinger, 2010), these pairs were not included in the analyses of the ERP data. The early midfrontal old/new effect, the putative correlate of familiarity, is typically observed bilaterally at frontal electrodes around 300–600 ms post-stimulus. The left parietal old/new effect, associated with recollection, has a left parietal maximum around 500–800 ms post-stimulus. Given these specific topographic characteristics of early and late old/new

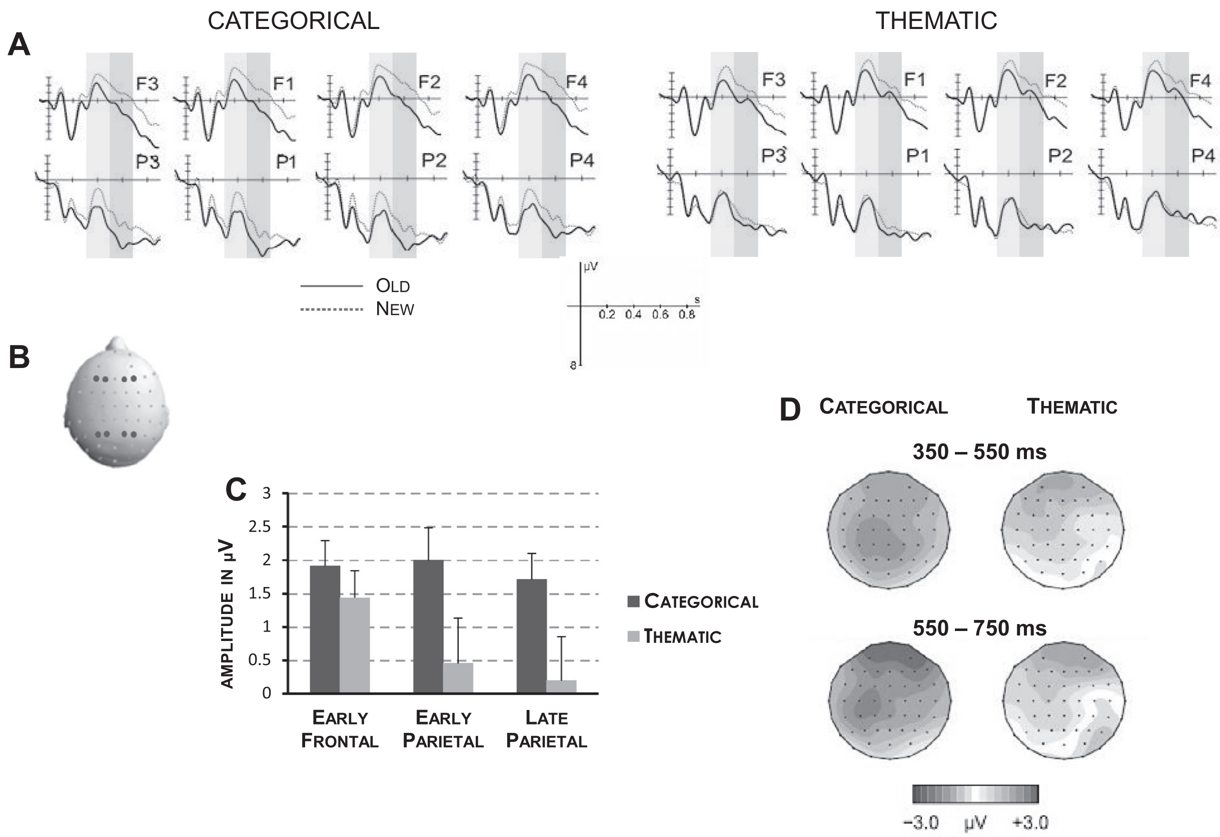

Fig. 1. Old/new effects observed during the test phase of Experiment 1 (negative voltages are plotted upwards). Panel A depicts grand average ERPs for correct old and new responses separated for the categorical and thematic conditions. Panel B highlights the sites of electrodes (F3, F1, F2, F4 and P3, P1, P2, P4) included into the analyses of the early and late old/new effects. Panel C shows the mean magnitude of the early midfrontal and parietal old/new effects (averaged over four frontal/parietal electrodes, respectively), and the left parietal old/new effect (each averaged over four parietal electrodes) separately for the categorical and thematic conditions. This is computed as the difference between correct old and correct new responses. Panel D shows topographic maps (as viewed from above) showing the scalp distribution of the differences between correctly responded to old and new pairs in the categorical and thematic conditions in the early (350–550) and late (550–750) time windows.

effects, electrodes from the following regions were defined for the analysis of the ERPs: left-frontal (F1, F3), right-frontal (F2, F4), left-parietal (P1, P3) and right-parietal (P2, P4) (Fig. 1B). In accordance with the temporal characteristics of the current effects, 350–550 ms and 550–750 ms windows were chosen for analyses. ERP analyses were restricted to trials from the categorical and thematic conditions that were correctly classified as "old" or "new". For topographic analyses, the data were normalized using the vector-scaling procedure as suggested by McCarthy and Wood (1985, see also Picton et al., 2000).

3. Results

3.1. Behavioral data

Table 3 summarizes hit rates (correct "old", Hit), correct rejection rates (correct "new", CR), false alarm rates to rearranged and new pairs erroneously endorsed as old (FA rearranged and FA new, respectively) for the categorical and thematic conditions, all computed according to Snodgrass and Corwin (1988).[2] Two types of Pr scores indexing old/new and associative discriminability are also reported.

The pattern of results shows higher recognition accuracy for categorical than thematic condition for both old and new pairs, as well as overall higher accuracy for new than old items. Two-way ANOVA with the factors Relation (categorical, thematic) and Type (Hit, CR) yielded a main effect of Relation, $F(1, 15) = 29.369$, $p < .01$, a main effect of Type, $F(1, 15) = 17$, $p < .01$, but no significant interaction between Relation and Type, $F(1, 15) = 2.402$, $p = .14$. To test for differences in participants' ability to discriminate between old/new and old/rearranged pairs, discrimination old/new and associative Pr indices were computed separately for each participant. Old/new Pr score was computed by subtracting false alarms to new pairs endorsed as old from the hit rate, and associative Pr was derived by subtracting false alarms to rearranged items classified as old from the hit-rate. Pairwise comparisons revealed better old/new discrimination following categorical than thematic pairs, $t(15) = 4.058$, $p < .01$, but no significant differences in associative discriminability, $t(15) = .314$, $p = .76$. The latter result was driven by a higher FA rate in the rearranged categorical than thematic condition, $t(15) = 4.051$, $p < .01$, which suggests that participants were more likely to endorse rearranged pairs as old in the categorical than in the thematic condition. There were no reliable differences in tendency to endorse new items as old across the conditions, $t(15) = .202$, $p = .843$. Averaged rearranged and new FA scores were used to compute a bias measure [Br = FA/(1−(Hit−FA)] which revealed a more liberal response bias in the categorical (.50) than in the thematic condition (.34), $t(15) = 4.146$, $p = .001$.

[2] Prior to planned analyses, a three-way-ANOVA with factors Testing Session (session 1, session 2), Relation (categorical, thematic) and Type (Hit, CR) was conducted on the accuracy data, and separate two-way ANOVAs with factors Testing Session (session 1, session 2) and Relation (categorical, thematic) were performed on the overall and associative Pr-scores to ensure that testing sessions did not differ with respect to performance. As none of the analyses revealed an effect of Testing Session or interactions involving this factor, all *p*-values > .05, all further analyses were conducted on the data collapsed across the two sessions.

Table 3
Behavioral assessment of memory performance.

	Hit Rate	CR Rate	FA new	FA rear.	Pr old-new	Pr associat.	RT	
							Hit Old	CR
Categorical	.75 (.03)	.87 (.02)	.04 (.01)	.43 (.03)	.72 (.03)	.32 (.03)	1557 (49)	1446 (41)
Thematic	.64 (.04)	.83 (.03)	.04 (.01)	.30 (.02)	.60 (.05)	.34 (.05)	1613 (60)	1461 (38)

Mean hit (the proportion of correctly endorsed as "old" studied pairs) and correct rejection (CR) rates (the proportion of correctly rejected as "new" unseen pairs) are reported together with corresponding mean reaction times (standard error in brackets). In addition, two types of false alarm rates are reported: those elicited by incorrectly endorsing new (new) or rearranged (rear.) pairs as old. Pr scores indexing old-new and associative discriminability were computed by subtracting the two types of false alarms (FA new, FA rearranged, respectively) from the hit-rates (standard error).

The pattern of results for accuracy data is mirrored in the reaction time data (see Table 3). Reaction times for the categorical pairs were faster than for the thematic pairs, and faster for new compared to old pairs. An ANOVA with the factors Relation (categorical, thematic) and Type (Hit, CR) revealed a main effect of Relation, $F(1, 15) = 7.742$, $p = .01$, as well as a main effect of Type, $F(1, 15) = 9.173$, $p < .01$, but no significant Relation by Type interaction, $F(1, 15) = 1.14$, $p = .30$.

Additionally, confidence ratings that followed correct responses to old and new items were compared for the categorical and thematic conditions in order to ensure that the differences in memory performance cannot be explained by simple changes in confidence strength. Since confidence ratings required a binary response (either "sure" or "unsure"), meaning that the probability of high-confidence responses was conditional on the probability of low-confidence responses, only "sure" responses were analyzed. Probabilities of "sure" responses to correct old and new judgments in categorical condition [mean values with standard error of the mean are .93 (.02) and .86 (.03), respectively] were compared with those to thematic items [mean values with standard error of the mean are .92 (.02) and .82 (.04), respectively]. An ANOVA with factors Relation (categorical, thematic) and Type (Hit, CR) revealed only a main effect of Type, $F(1, 15) = 5.564$, $p = .03$, suggesting that, for correct responses, participants felt more confident when accepting items as old rather than rejecting them as new pairs. No main effect of Relation and no interaction with this factor were found, all p-values > .12, indicating the confidence with which participants made their responses did not differ across the conditions.

3.2. ERP data

Grand average ERP waveforms at electrodes F1, F2, F3, F4 and P1, P2, P3, P4 separated for the categorical and thematic conditions are shown in Fig. 1A. Upon visual inspection, there appear to be robust differences in the pattern of results for the two relations: Old/new differences are pronounced in the early time window at frontal electrodes for both conditions, although this is topographically more broadly distributed for categorical relations. Also, old/new differences at parietal sites in the late time window are present only for the categorical relation. To check the statistical validity of the visually observed dissociation, initial ANOVAs were conducted for the early and late time windows separately with the factors Relation (categorical, thematic), Type (Hit, CR), Location (frontal, parietal), Hemisphere (right, left) and Site (inferior, superior).

3.2.1. 350–550 ms

The initial ANOVA revealed a main effect of type, $F(1, 15) = 24.328$, $p < .001$ and a five-way interaction between factors Relation, Type, Location, Hemisphere and Site, $F(1, 15) = 5.321$, $p = .04$. In line with the typical frontal distribution of the early mid-frontal old/new effect, subsequent analyses were conducted separately at frontal and parietal locations. At frontal locations, where the ERP correlate of familiarity is typically observed, there was a main effect of Type, $F(1, 15) = 35.137$, $p < .001$, and a four-way interaction between Relation, Type, Hemisphere and Site, $F(1, 15) = 4.730$, $p = .05$. To resolve the latter interaction, separate analyses were conducted at each frontal electrode for the categorical and thematic conditions as a function of Type. There was an effect of Type at each of the four electrodes for both categorical and thematic items, all p-values < .01 suggesting that ERP waveforms to old items were reliably different from those to new items on all frontal sites irrespective of relationship condition. That the ERP correlate of familiarity did not differ in size according to relation conditions, however, was confirmed by directly comparing the magnitude of the old/new effects ("old minus new") averaged across the frontal electrodes (Fig. 1C), $t(15) = .879$, $p = .39$.

At parietal locations in this time window, there was a main effect of Type, $F(1, 15) = 10.034$, $p < .01$ with a Relation by Type interaction which approached significance, $F(1, 15) = 3.161$, $p = .10$. The pattern presented in Fig. 1A indicates the presence of parietally distributed old/new effect in the categorical but not in the thematic condition, and subsidiary paired t-tests were employed in order to determine whether this was the case. The results confirmed the visual observation of early old/new differences in the categorical, $t(15) = 4.177$, $p < .01$, but not in the thematic condition, $t(15) = .681$, $p = .50$ (averaged across all parietal sites).

3.2.2. 550–750 ms

The initial analysis in this time window revealed a main effect of Type, $F(1, 15) = 22.638$, $p = .001$, a marginally significant Relation by Type interaction, $F(1, 15) = 3.888$, $p = .07$, and a marginally significant four-way interaction between the factors Relation, Type, Location and Site, $F(1, 15) = 4.229$, $p = .06$. Although the ERP correlate of recollection is associated with a parietally distributed old/new effect in this time window, visual inspection of the waveforms in Fig. 1A also indicated the presence of the old/new effects at frontal locations. To examine this, separate ANOVAs for frontal and parietal locations with the factors Relation, Type, Hemisphere and Site were conducted. At frontal locations, all old and new ERPs diverged from one another regardless of Relation condition, as manifested by a main effect of Type, $F(1, 15) = 9.192$, $p < .01$. There was no main effect and no interactions involving the factor Relation, all p-values > .18. In contrast, at parietal locations a significant Relation by Type interaction was found, $F(1, 15) = 5.003$, $p = .04$. Paired contrasts of the data collapsed across the factors Hemisphere and Site, revealed a significant old/new effect for categorical, $t(15) = 4.467$, $p < .001$, but not for the thematic condition, $t(15) = .296$, $p = .77$. In line with this pattern, Fig. 1C shows the "old minus new" differences averaged across all parietal sites separately for the categorical and thematic conditions which were larger for categorical than thematic condition, $t(15) = 2.237$, $p = .04$.

3.2.3. Topographic analyses

Topographic analyses were conducted to determine whether there was a qualitative difference in the scalp distributions of the two relation conditions in the early and late time windows (Fig. 1D). These analyses were performed on vector-scaled

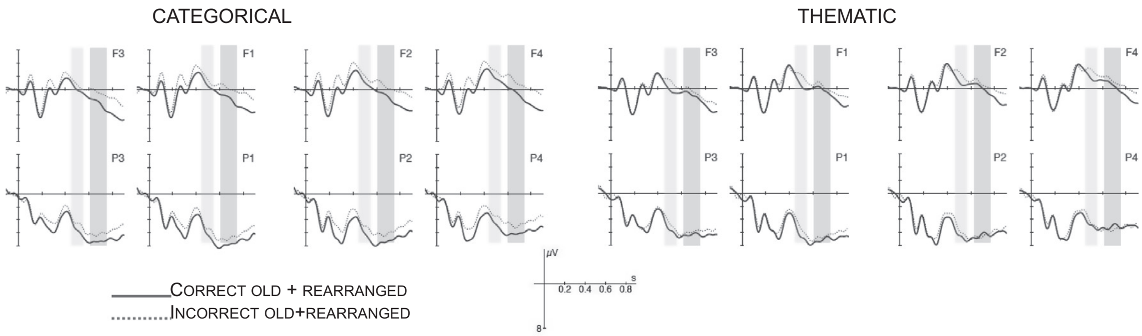

Fig. 2. Grand average ERPs for correctly and incorrectly responded to old and rearranged pairs in the categorical and thematic conditions. Negative voltages are plotted upwards.

difference waveforms (old minus new) from the 350–550 and 550–750 ms windows from the same array of electrodes at frontal (F3, F1, F2, F4) and parietal locations (P3, P1, P2, P4) as those chosen for the analysis of ERP waveforms. ANOVAs with the factors Relation (categorical, thematic), Location (frontal, parietal), Hemisphere (right, left) and Site (inferior, superior) were conducted on the data from the early and late time windows separately. There was a four-way interaction in the early time window, $F(1, 15) = 5.511$, $p = .033$, and a Relation by Hemisphere by Location in the late time window, $F(1, 15) = 6.227$, $p = .025$, pointing to differences in the spatial characteristics of the early and late old/new effects in the categorical and thematic conditions.

3.2.4. Comparison of correct and incorrect old and rearranged responses

Old/new contrasts alone do not afford strong inferences about the extent to which the current processes supported discrimination of old and rearranged pairs. In light of this, an additional post hoc analysis was conducted. An insufficient number of correct responses in the rearranged condition precluded a classical old vs. rearranged contrast, but it was possible to contrast correct and incorrect responses to old and rearranged word pairs. Incorrect responses refers here to old items endorsed as rearranged and rearranged pairs endorsed as old. These conditions are equated for item familiarity, so any differences between them should be attributed to processes which support associative discrimination (either via recollection and/or associative familiarity). The data from 2 participants were discarded from the analysis following fewer than 10 trials in one of the conditions. The mean number of trials for the correct and incorrect responses in the categorical condition was 42 (range 33–56) and 22 (range 14–34), respectively, and 41 (range 30–52) and 19 (range 14–22) in the thematic condition. Fig. 2 shows these contrasts, which indicate differences between correct and incorrect categorical items which are most robust in later time windows over parietal sites. In contrast, these ERP contrasts differ only over frontal sites in an earlier time window in the thematic condition. In line with the presence of a parietal effect only for categorical pairs in the principal analyses above, an ANOVA with factors Type (correct, incorrect), Hemisphere and Site on the data from the parietal electrodes (P3, P1, P2, P4) in the 600–750 ms time window, revealed a marginally significant main effect of type in the categorical, $F(1, 13) = 3.257$, $p = .094$, but not in the thematic condition, $p > .146$. Differences between incorrect and correct thematic ERPs appear most robust from 450 to 550 ms over frontal sites and in line with this, ANOVA on the data from the frontal electrodes (F3, F1, F2, F4) revealed a main effect of Type in the thematic condition, $F(1, 13) = 5.485$, $p = .036$, whereas no effect or interactions with Type were observed in the categorical condition, all $p > .16$, for this time window.

3.2.5. New item ERP comparisons

The preceding analyses revealed that the early midfrontal old/new effect was not modulated by relation type. It is possible, however, that differences in the size of the early midfrontal old/new effect for the two relation types may have been masked by simultaneously acting semantic memory processes as indexed by the N400 component. The N400 is a negative-going ERP component observed over centroparietal sites 300–500 ms post-stimulus that is attenuated with facilitated semantic processing (Kutas & Federmeier, 2000, 2011; Lau, Phillips, & Poeppel, 2008) such as when a target is preceded by a related prime (Brown and Hagoort, 1993; Bentin et al., 1995) compared to an unrelated one. Even though word pairs were presented simultaneously in the present experiment, the leftmost word could have acted as a prime for the rightmost word (for a similar argument see Rhodes & Donaldson, 2007), and critically, the extent to which this occurred could have differed for categorical and thematic pairs. Such modulations in the N400 may have masked potential between-condition differences for the early midfrontal old/new effect. To address this possibility, ERP waveforms elicited by correctly rejected new categorical and thematic items as well as unrelated fillers included as a baseline[3] were analyzed. New items are not confounded by the retrieval of episodic details from the study phase ensuring that any differences in their waveforms can be taken to reflect changes in semantic priming. A four-way ANOVA with factors Relation (categorical, thematic, unrelated), Location (frontal, parietal), Hemisphere (left, right) and Site (inferior, superior) was conducted on grand average waveforms of the correctly rejected new items from the same time window as that chosen for the analysis of the early midfrontal old/new effects (350–550 ms post-stimulus). The analysis revealed no effect of Relation and no interactions involving this factor, all p-values > .15. Further visual inspection of the waveforms (Fig. 3) suggests that N400 semantic priming effects could have taken place in a smaller time window, from approximately 350–470 ms post-stimulus. In this time window all three relation-types evoked a negative-going peak which we identify with the N400, and which was attenuated for the thematically related pairs on the parietal sites.

To determine whether this pattern held statistically, a second ANOVA limited to this shorter time window was conducted and revealed a three-way interaction between Relation, Location and Site, $F(2, 30) = 3.262$, $p = .05$, all other p-values > .15. To resolve the interaction, paired samples t-tests were employed on the data from frontal and parietal locations, separately, collapsed across factor Hemisphere. No relation-related modulation of the waveforms was observed at frontal superior and inferior sites, all p-values > .61. At parietal sites, at both inferior and superior sites, there

[3] The mean number of trials per participant in the unrelated condition was 27 (range 17–36).

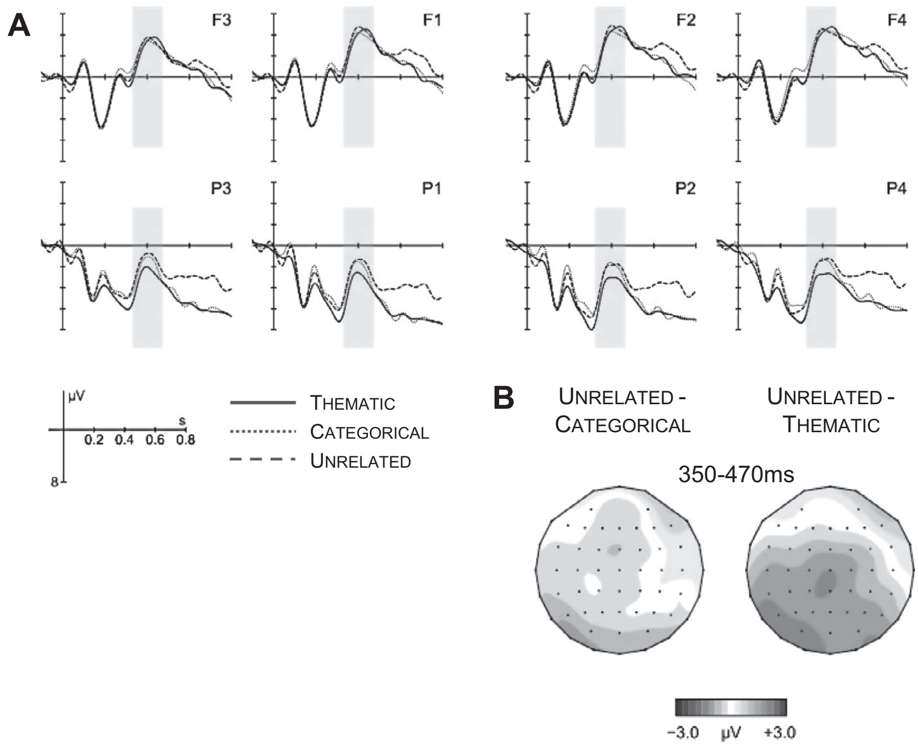

Fig. 3. ERPs elicited by correctly rejected new items in the categorical, thematic and unrelated conditions taken to reflect semantic N400 (negative voltages are plotted upwards). Panel A shows grand average ERPs and panel B illustrates the scalp distribution of the unrelated minus categorical and unrelated minus thematic differences in the 350–470 ms time window.

was no evidence of differences between categorical and unrelated pairs, both p-values > .7, but comparisons between thematic and unrelated pairs were significant at inferior and superior sites, $t(15) = 2.421$, $p = .03$, and $t(15) = 2.344$, $p = .03$ (one-tailed), respectively. In addition, ERPs tended to be more negative going in the categorical than in the thematic relation at superior parietal sites, $t(15) = 1.523$, $p = .08$ (one-tailed). These results demonstrate that semantic priming effects did differ for the two relation types, as reflected in an attenuated negativity to thematic pairs as compared to unrelated and categorical pairs. This interaction was limited to parietal sites in line with the typical distribution of the N400. Notably, there was no evidence that semantic priming modulated ERPs at frontal locations in the early time window.

4. Discussion

A standard associative recognition memory test was conducted to explore whether pre-existing categorical and thematic relationships between paired concepts differentially affect familiarity- and recollection-based recognition, as indexed by their putative electrophysiological signatures. The results revealed a higher hit-rate in the categorical condition accompanied by a higher proportion of false alarms to rearranged pairs resulting in a more liberal response bias. Comparable performance on new word pairs was observed in both conditions. Associative recognition of both relation types was accompanied by robust early midfrontal old/new effects which were dissociable from ERP correlates of semantic priming observed for thematic relations in the early time window at posterior sites. A left parietal old/new effect was present in the categorical condition only. The data provide novel evidence for the differential modulation of associative recognition by categorical and thematic relations, and are consistent with an interpretation which states that whilst the recognition of categorical associations necessitates recollection, familiarity alone might be sufficient for thematic relations.

4.1. Associative recognition of semantically related concepts

In accordance with prior studies (Greve et al., 2007; Opitz & Cornell, 2006; Rhodes & Donaldson, 2008) both familiarity and recollection were expected to contribute to associative recognition of categorical and thematic relations. The critical assumption underlying the current comparison was that the capability of thematic associates to support integrative processing (Badham et al., 2012; Estes & Jones, 2009; Wisniewski & Bassok, 1999) might foster the contribution of familiarity to associative recognition of relations of this type. Contrary to this prediction however, no enhancement of the ERP correlate of familiarity was observed for thematic pairs. At the same time, however, the left parietal old/new effect was not reliable for these items although it was present in the categorical condition. Even though the pattern at the first glance is surprising, the early midfrontal old/new effect in the absence of the left parietal effect in the thematic condition is in line with the notion that familiarity alone may have been sufficiently diagnostic for associative recognition of this type of pair. Research on unitization strategies demonstrates that with repeated exposure, connections between separate elements (e.g., two stems of a compound word) are strengthened to such an extent that elements and their associations become perceived as components of a coherent gestalt (Graf & Schacter, 1989; Mecklinger & Jäger, 2009; Quamme et al., 2007; Yonelinas, Kroll, Dobbins, & Soltani, 1999; Yonelinas et al., 2010). It has been shown that associative recognition of such items can occur on the basis of familiarity (Henke, 2010; Quamme et al., 2007; Yonelinas et al., 2010). Whilst a body of research on unitization has employed experimentally and pre-experimentally established compounds (Bader et al., 2010; Ford, Verfaellie, & Giovanello, 2010; Giovanello et al., 2006; Quamme et al., 2007), other configurations of items have been shown to comprise coherent representations and behave similarly during recognition, e.g. items and their colors (Diana, Yonelinas, & Ranganath, 2008), configurations of facial parts (Yonelinas et al., 1999) and pairs of morphed faces of the same person (Jäger et al., 2006). Even though it is currently unclear under which circumstances episodic familiarity may have an impact upon the presence or amplitude of the left parietal old/new effect, the current data imply that thematic relations may allow individual concepts to be organized into coherent scenes that can be principally recognized on the basis of episodic familiarity and to some extent bypass recollective processing.

Correct recognition of categorically related pairs was associated with reliable early and late old/new effects that were topographically different from the effects in the thematic condition. The early effect was rather broadly distributed and showed two maxima, over both frontal and parietal locations. One possibility is that the posterior aspect of this component reflects early onsetting recollective processing. The reliable early frontal old/new effect supports the proposal by Greve et al. (2007) that familiarity is engaged in associative recognition of categorical relations. Nonetheless, an important question is why associative recognition in this condition, in contrast to thematic pairs, is associated with a robust ERP index of recollection.[4] As theorized by Markman and Wisniewski (1997) and supported by various rating studies (Estes et al., 2011; Lin & Murphy, 2001; Murphy, 2001) including the current rating data, categorically related concepts of the same ontological level are characterized by a high degree of semantic similarity. Each set of three categorical items in the present experiment, e.g., *dancer–singer–actor*, shared a number of semantic commonalities, leading to a high degree of feature overlap between old (e.g. *dancer–actor*) and rearranged pairs (*singer–actor*). This similarity may be the reason for participant's diminished ability to discriminate between old and rearranged pairs that biased them to respond "old" to rearranged pairs boosting the number of false alarms as suggested by higher false alarm rates and a more liberal response criterion in the categorical condition (for a similar result see Greve et al., 2007; Patterson et al., 2009; Rhodes & Donaldson, 2007). Accordingly, old (e.g., *dancer–stage*) and lure pairs (*singer – stage*) in the thematic condition may not have encouraged false recognition to the same degree because the different themes they belong to (*ballet* vs. *concert*) may make them more distinct. In line with this are experiments that used modifications of the Deese–Roediger–McDermott paradigm and which have reported that both categorical and thematic lists are prone to false recognition (Knott, Dewhurst, & Howe, 2012; Park, Shobe, & Kihlstrom, 2005) but that distinctiveness might be an important parameter that can reduce this (Israel & Schacter, 1997; Schacter, Israel, & Racine, 1999). It may have been possible to employ a distinctiveness heuristic of this kind for the thematic condition in the present study, allowing familiarity to be sufficient for discrimination between distinct thematic relation-types. This is unlikely to be the case for categorical pairs. When representations of studied and unstudied items strongly overlap, familiarity strength also increases for lures, making differences in the familiarity levels too subtle to distinguish between them (Curran, 2000; Mecklinger, 2000; Nessler, Mecklinger, & Penney, 2001; Yonelinas, 2002). In contrast, as shown by prior ERP (Curran, 2000; Nessler et al., 2001) and behavioral studies (Patterson et al., 2009; Dosher & Rosedale, 1991) recollection can support this discrimination by delivering the specific information about the prior occurrence.

There may be, however, alternative interpretations of the ERP correlates of recollection in the categorical condition. One possibility is to relate the ERP correlate of recollection to the enhanced memory performance in this condition in light of previous studies which show a robust relationship between better memory performance and a greater involvement of recollection in recognition tests (Rugg et al., 1998; Ullsperger, Mecklinger, & Müller, 2000). Although it is not possible to exclude this possibility, a post hoc analysis restricted to those participants ($n = 10$) for whom hit rates were comparable in the two conditions (categorical: .76(.03), thematic: .70(.04), $t(9) = 1.719$, $p = .12$) also confirmed the specificity of the left parietal old/new effect to the categorical condition only. A further analysis on correct and incorrect ERPs also speaks against this interpretation. Associative recognition was operationalized in the principal analyses as an ERP contrast between correct responses to old and new pairs, as has often been employed in associative recognition memory studies (Bader et al., 2010; Greve et al., 2007; Rhodes & Donaldson, 2007). Nonetheless, contrasting old and rearranged conditions is likely to provide a purer measure of associative processing (Donaldson & Rugg, 1998). Comparing correct and incorrect responses to old and rearranged pairs should likewise be indicative of associative recognition since all words in these contrasts would be equated for item familiarity and, yet, correct responses should differ from incorrect ones due to a presence of a memory for a relational link between the concepts. An additional analysis of this type revealed that the early midfrontal old/new effect differentiated correct and incorrect old + rearranged responses for thematically – but not categorically-related concepts whereas the trend was in the opposite direction for the left parietal old/new effect. The outcome of this analysis thus provides additional evidence that semantic relations may engage recollection, but also familiarity to a different extent. It supports the conclusion that in the case of thematic pairs, familiarity, the least demanding recognition process, is sufficiently diagnostic for associative discrimination.

4.2. Dissociating episodic familiarity and semantic priming effects

Interpretations of the current ERP data rest on the assumption that the early midfrontal old/new effect manifests explicit familiarity-based recognition (Bridger et al., 2012; Rugg & Curran, 2007; Stenberg, Hellman, Johansson, & Rosen, 2009). It is also possible, however, that this early old/new effect is superimposed by processes related to semantic priming. These processes are reflected in the N400, which is typically attenuated following words that are congruent with the preceding context compared to those that are not (Bentin, Kutas, & Hillyard, 1995; Brown & Hagoort, 1993; Kutas & Federmeier, 2000; Kutas & Federmeier, 2011) and which is observed in a time window that overlaps with the early old/new effect. Some researchers argue that the early midfrontal old/new effect provides an index of conceptual priming (Paller et al., 2007; Voss & Federmeier, 2011). Given prior evidence that categorical and thematic relations might show differences in semantic processing observed in semantic priming effects (Deacon et al., 2004; Koivisto & Revonsuo, 2001; Sass et al., 2009), the N400 may have been differentially modulated by the two types of relations in the current experiment, possibly affecting the early old/new effects. The semantic manipulation employed here provided an opportunity to address this possibility. It was assumed that whereas the old/new effects should index successful episodic memory effects, contrasts between new items should reflect different levels of semantic priming of the leftmost to the rightmost word of the pair as reflected in the N400. Whereas semantic relationship did not modulate the ERP waveforms in the 350–550 ms time window, restricting the analyses to 350–470 ms windows in accord with visual inspection revealed a N400 modulation at

[4] Typically, recollection-based responses are expected to attract more high-confidence judgments in recognition tests that familiarity-based responses (Yonelinas, 2002). In the present experiment, no confidence advantage in the categorical condition was observed. A very high proportion of "sure"-hits in both conditions (approximately .92) suggests that the binary confidence scale employed here may not have been sensitive enough to capture this aspect.

parietal electrodes, where there was an attenuation for the thematic condition compared to unrelated and categorical new items in line with facilitated access for the second word for thematically related pairs. This semantic memory effect was dissociable from the pattern observed over frontal sites where there was no interaction with relation-type. This outcome has several important implications. Firstly, it makes it unlikely that the midfrontal component of the early old/new effects in the categorical and thematic conditions could have been confounded by changes in semantic priming. Secondly, it shows that the attenuated left parietal old/new effect in the thematic condition cannot be attributed to the reduced negativity to new thematic pairs as this pattern was observed in a restricted and relatively early time window ending around 470 ms. Thirdly, the results support the previously reported functional and topographic dissociation between the N400 and the midfrontal old/new effect (Bridger et al., 2012) and also speak against the direct link between the N400 semantic priming effect observed over posterior sites in the present experiment and an episodic early midfrontal old/new effect.

5. Conclusions

Taken together, our findings add to those data points which demonstrate that semantic memory interacts with episodic memory by showing that particular pre-existing semantic relations impact with the episodic memory processes that support associative recognition. In line with previous findings (Greve et al., 2007; Rhodes & Donaldson, 2008) the current electrophysiological data indicate that both familiarity and recollection play a role in associative recognition of categorically related concepts. In contrast, the contribution of recollection was attenuated when paired concepts could be integrated into bound thematic representations, suggesting that familiarity may be sufficiently diagnostic to support associative recognition for this kind of semantic relationship.

Acknowledgments

We gratefully acknowledge Iris Wiegand for assisting with data collection and Bertram Opitz and Regine Bader for their highly valuable comments. This research was supported by a grant from German Research Foundation (IRTG 1457).

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