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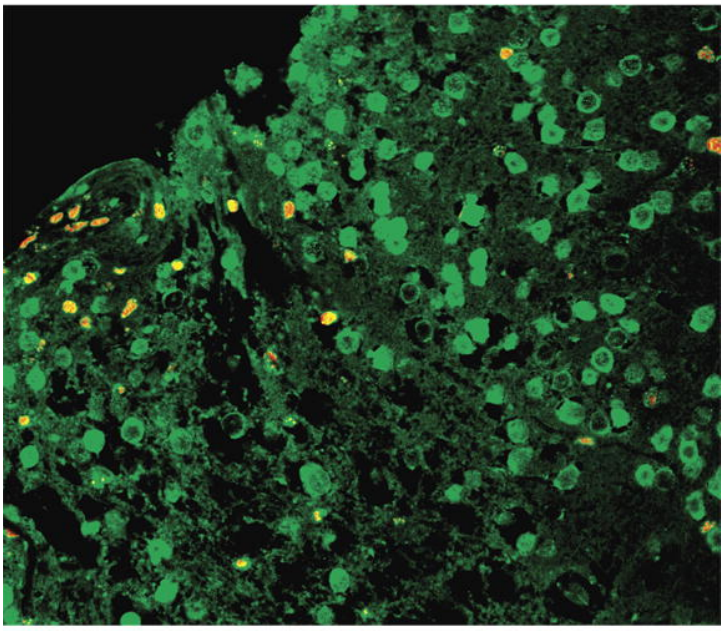

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Research Report

The influence of object and background color manipulations on the electrophysiological indices of recognition memory

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ABSTRACT

In a recognition memory experiment, the claim was tested that intrinsic object features contribute to familiarity, whereas extrinsic context features do not. We used the study–test manipulation of color to investigate the perceptual specificity of ERP old–new effects associated with familiarity and recollection. Color was either an intrinsic surface feature of the object or a feature of the surrounding context (a frame encasing the object); thus, the same feature was manipulated across intrinsic/extrinsic conditions. Subjects performed a threefold (same color/different color/new object) decision, making feature information task-relevant. Results suggest that the intrinsic manipulation of color affected the mid-frontal old–new effect associated with familiarity, while this effect was not influenced by extrinsic manipulation. This ERP pattern could not be explained by basic behavioral performance differences. It is concluded that familiarity can be perceptually specific with regard to intrinsic information belonging to the object. The putative electrophysiological signature of recollection – a late parietal old–new effect – was not present in the data, and reasons for this null effect are discussed.

1. Introduction

Dual process theories of recognition memory assume that there are two distinct processes contributing to the ability to assess the prior occurrence of objects: familiarity and recollection. The concept of familiarity refers to an automatically arising, undifferentiated feeling of having encountered something (or someone) before, with no retrieval of specific spatiotemporal detail regarding the prior encounter. Recollection, on the other hand, is thought of as a more controlled process that provides specific information about past episodes. Evidence concerning this distinction is extensively reviewed elsewhere (Ecker et al., 2004, 2007b; Groh-Bordin et al., 2005; Woodruff et al., 2006; Yonelinas, 2002; but see Dunn, 2004).

Importantly for the present paper, the two processes have been associated with distinct event-related potential (ERP) effects, because these electrophysiological correlates covary with behavioral indices such as Remember/Know measures (Smith, 1993) or depth-of-processing manipulations (Rugg et al., 1998a). Familiarity is assumed to be reflected in a quite early ERP old–new effect arising mainly at mid-frontal electrodes from about 300 to 500 ms (the FN400 effect), whereas recollection has been linked to a later left-parietal effect (the LPC effect), usually occurring around 500 to 800 ms. For both effects, ERP waveforms elicited by old objects in the test phase of a standard old/new recognition memory experiment are usually more positive than ERPs elicited by new items (cf. Friedman and Johnson, 2000; Mecklinger, 2000; Zimmer et al., 2006 for reviews).

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Source memory – the ability to retrieve not only an item but also its source, for instance, the list it occurred in – is the hallmark of *recollection* (e.g., Rugg et al., 1998b); thus, the retrieval of specific feature information (also often referred to as source memory itself) is usually assigned to recollective processing. In fact, many ERP studies have reported an influence on the LPC effect associated with recollection when asking subjects to retrieve source information, that is, a larger LPC effect if not only the item but also its source is correctly (vs. incorrectly) retrieved (Trott et al., 1997; Smith, 1993; Wilding and Rugg, 1996; Wilding, 1999). In a color memory study, Cycowicz et al. (2001) presented colored line drawings at study which were then tested in black and found that the LPC effect associated with correct source retrieval showed a different topography compared to incorrect source judgments. Although the authors tended to interpret this as a qualitative processing difference, recollection very likely relies on the activity of a fronto-temporo-parietal network (Aggleton and Brown, 1999, 2006; Iidaka et al., 2006), so slight topographical differences may simply arise from relatively different contributions of different subcomponents or regions (Otten and Rugg, 2005). Importantly for the present study, the LPC effect is usually smaller if a specific feature is changed from study to test (Curran, 2000; Curran and Cleary, 2003; Ecker et al., 2007b; Groh-Bordin et al., 2006; Ranganath and Paller, 1999).

Yet, despite earlier null effects of perceptual manipulations on the putative ERP correlate of *familiarity* (Curran, 2000; Curran and Cleary, 2003), we have recently proposed that the representation subserving familiarity can also contain specific sensory feature information, as long as this information is intrinsic, that is, belonging to the object (e.g., the color or orientation of an object; see Ecker et al., 2004; Groh-Bordin et al., 2005, 2006). The reason to assume this is that apparently objects (and their intrinsic features) have a special status in both perception and memory. For instance, in an fMRI study, O'Craven et al. (1999) found that attending to one feature of an object enhances the neural representation not only of the attended feature, but also of other features of that object. This suggests that attention preferably selects whole objects for further processing, so objects are also likely to constitute units of memory. Further support for the link of rather automatic familiarity and intrinsic perceptual information can be found in behavioral studies on color memory. Wilton (1989) found better color recognition for surface vs. background color even following incidental study. Similarly, Walker and Cuthbert (1998) found incidental memory effects of color only if color and shape were unitized, that is, color was part of the perceptual unit of the item (see also Guillem et al., 2001; Zimmer and Steiner, under review).

We were able to underscore the claim that familiarity processing can also be perceptually specific in a recent recognition memory study, in which either the color of objects or the shape of arbitrary gray backgrounds was manipulated (Ecker et al., 2007b; also see Ecker et al., 2007a). The task was an inclusion task (i.e., instructions were to accept both copy cues and perceptually manipulated old items as "old"), so feature information was basically irrelevant. Nevertheless, results showed that only the manipulation of the intrinsic feature affected the FN400 ERP effect associated with familiarity, whereas the manipulation of the extrinsic feature did not, even if the LPC effect associated with recollection was affected. Also, only the intrinsic manipulation had an effect on accuracy and reaction time measures in this inclusion task, in line with previous behavioral research (Jolicoeur, 1987;

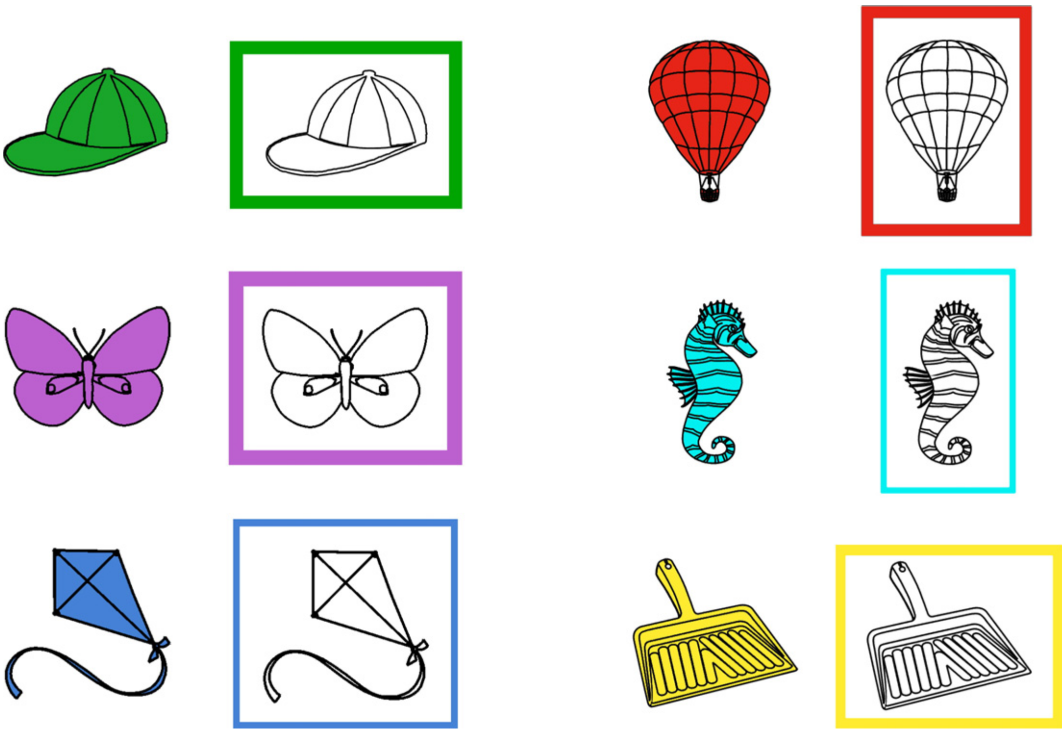

Fig. 1 – Examples of items used.

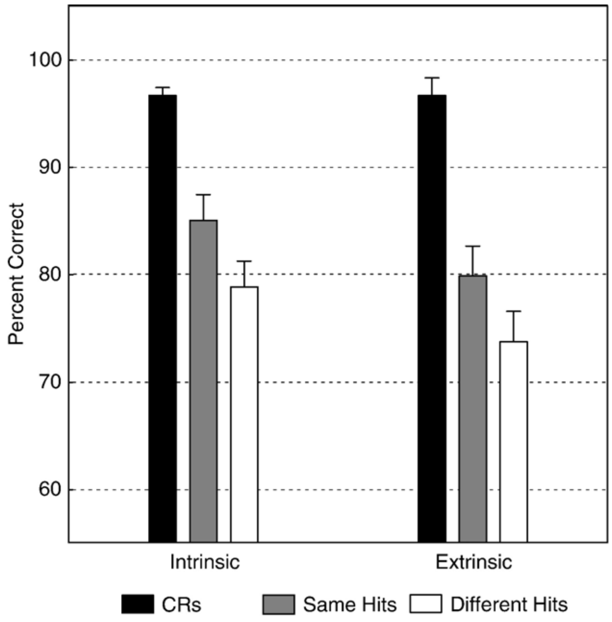

Fig. 2 – Recognition memory performance in the Intrinsic and Extrinsic conditions. CRs denotes correct rejections of new items. Vertical bars denote standard errors of the mean.

Zimmer, 1995; Zimmer and Steiner, 2003). This was taken as evidence for the involuntary activation of intrinsic as opposed to extrinsic information in the course of familiarity processing.

The aim of the present study was to corroborate previous findings of perceptual specificity for intrinsic information only, and to extend these to test situations with direct feature relevance. Another aim was to contrast the manipulation of intrinsic and extrinsic feature manipulations while keeping perceptual conditions as similar as possible. In the Ecker et al. (2007b) study, the intrinsic feature was color and the extrinsic feature was shape of background. Manipulating shape as an intrinsic feature would mean to distort the object itself; thus, we decided to design an experiment in which color was manipulated both as an intrinsic and an extrinsic feature, holding all other factors constant. Therefore, objects were either presented as colored silhouettes or as black line drawings encased by a colored frame (Intrinsic vs. Extrinsic conditions; see Fig. 1); color was manipulated between study and test for a subset of old items (Same vs. Different repetitions; see Section 4 for details).

Hypotheses were that in the Intrinsic case, a color manipulation should affect performance (i.e., primarily RTs[1]) and the FN400 ERP old–new effect associated with familiarity. That is, in case of a change in intrinsic color, RTs should increase and the FN400 effect should decrease in magnitude. Because color information was relevant for subjects' decision, we expected a similar effect on the LPC effect associated with recollection, as well. In the Extrinsic case, we predicted that the manipulation should not affect the FN400 effect, but should only influence the LPC effect and behavioral performance (again, primarily RTs).

2. Results

2.1. Behavioral results

Accuracy data are depicted in Fig. 2. Differing from the figure, analysis was based on corrected recognition scores (Pr-score = hit rate − false alarm rate; Snodgrass and Corwin, 1988), as these offer a better estimate of true performance level. Pr-scores were .73 for Intrinsic/Same, .67 for Intrinsic/Different, .70 for Extrinsic/Same, and .65 for Extrinsic/Different conditions, respectively. Performance was well above chance in all conditions, all $t(31) > 15.24$, $MSE < 0.05$, $p < 0.001$. In a 2×2 ANOVA with the factors Congruency (Same vs. Different) and Intrinsic/Extrinsic, there was a main effect of Congruency, $F(1,31) = 14.77$, $p < 0.001$, indicating better performance for Same repetitions. Performances did not differ reliably between the Intrinsic and Extrinsic conditions, and there was no interaction, both $F(1,31) < 1$.

Reaction time data are depicted in Fig. 3. New items were rejected rather quickly, response times were 839 ms in the Intrinsic and 892 ms in the Extrinsic case, the latter being significantly slower, $F(1,31) = 11.01$, $p < 0.01$. Given the experimental hypotheses, further analysis of reaction times was restricted to hits. Mean hit reaction times were 1008 ms for Intrinsic/Same, 1138 ms for Intrinsic/Different, 1105 ms for Extrinsic/Same, and 1263 ms for Extrinsic/Different conditions, respectively. Thus, in the analysis of reaction time data (analogue to accuracy data analysis), there were main effects of Congruency, $F(1,31) = 70.82$, $p < 0.001$, and Intrinsic/Extrinsic, $F(1,31) = 43.60$, $p < 0.001$, but no interaction, $F(1,31) = 2.28$, $p > 0.1$.

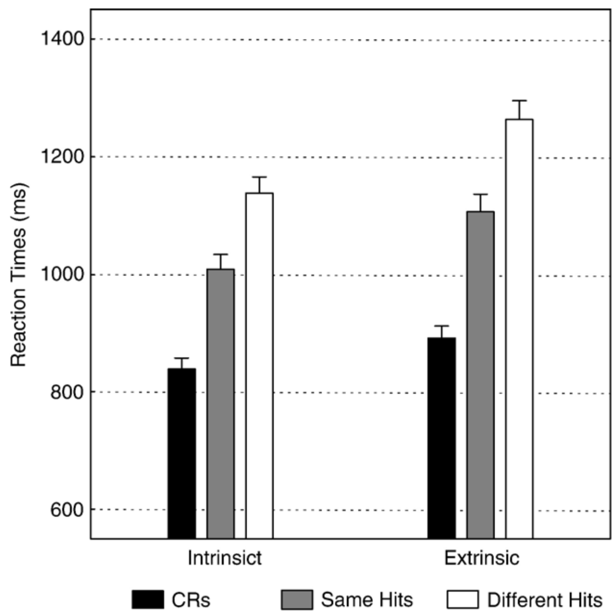

Fig. 3 – Mean response times in the Intrinsic and Extrinsic conditions. CRs denotes correct rejections of new items. Vertical bars denote standard errors of the mean.

[1] Note that even in the case of equally accurate feature memory across Same and Different conditions, an old object with a new color may lead to conflict and decision uncertainty. Thus, predictions were focused on the more sensitive RT measures, in line with the bulk of previous behavioral evidence, although an effect on accuracy was considered possible.

2.2. ERP data

As suggested by Dien and Santuzzi (2005), electrodes were grouped into nine regions of interest (ROIs) comprising three electrodes each (details see Section 4). Selected electrode sites were based on previous recognition memory research (e.g., Curran and Dien, 2003; Mecklinger, 1998, 2000; Rugg et al., 1998b; Tsivilis et al., 2001). ROIs constituted a three by three matrix, allowing for the utilization of the resulting three-level factors Anterior–Posterior (AP) and Laterality (Lat) in all analyses. Time windows corresponding to the old–new effects mentioned before were set to 300–500 ms and 500–700 ms, respectively, based on previous research and visual inspection of the data. Grand average waveforms are depicted in Figs. 4 and 5. In both Intrinsic and Extrinsic conditions, waveforms elicited by new and old items differ from about 300 ms onwards, especially at frontal sites. In the Intrinsic condition, this old–new effect is more pronounced for Same vs. Different repetitions. There was no evidence of a recollection-related LPC effect. Spherical spline-interpolated scalp maps of effects are shown in Fig. 6.

In Time window 1 (300–500 ms), an AP by Lat by Intrinsic/Extrinsic by Condition (New/Same/Different) MANOVA yielded a significant four-way interaction, $F(8,24)=2.58$, $p<0.05$. From inspection of Figs. 4 and 5 it seems that this interaction relies mainly on the apparently more widespread old–new effect for Intrinsic–Same repetitions, although the topographic pattern itself is very similar across conditions (Fig. 6). Comparing Intrinsic and Extrinsic conditions, the interesting interaction contrast between Same and Different amplitudes at the mid-frontal ROI was significant, $F(1,31)=5.10$, $p<0.05$. That is, mid-frontal Same and Different waveforms differed only in the Intrinsic condition in the first Time window. Table 1 shows the planned comparisons in both conditions.

This rather focussed follow-up analysis was justified by topographic inspection of difference waves in the Intrinsic condition. Visual inspection suggests that the congruency effect (Same–Different) has a more posterior distribution than the mid-frontal old–new effect (cf. Fig. 6). Such a topographic difference could imply that the feature manipulation is not modulating the FN400 effect itself, but an overlapping deflection. For instance, Intrinsic Same hits may be distinctively associated with some kind of early posterior recollective-like process, or implicit memory processing, which has also been linked to posterior ERP effects in similar time windows and regions (e.g., Rugg et al., 1998a). The simplest way to investigate whether the congruency effect can in fact be interpreted as affecting the mid-frontal old–new effect in a rather straightforward way is to directly test whether or not the Intrinsic/Extrinsic by Same/Different interaction contrast is selectively significant at the mid-frontal ROI. The result of this analysis is clear-cut: the interaction is reliable at the mid-frontal ROI, $F(1,31)=5.10$, $p<0.05$, but no other ROI,

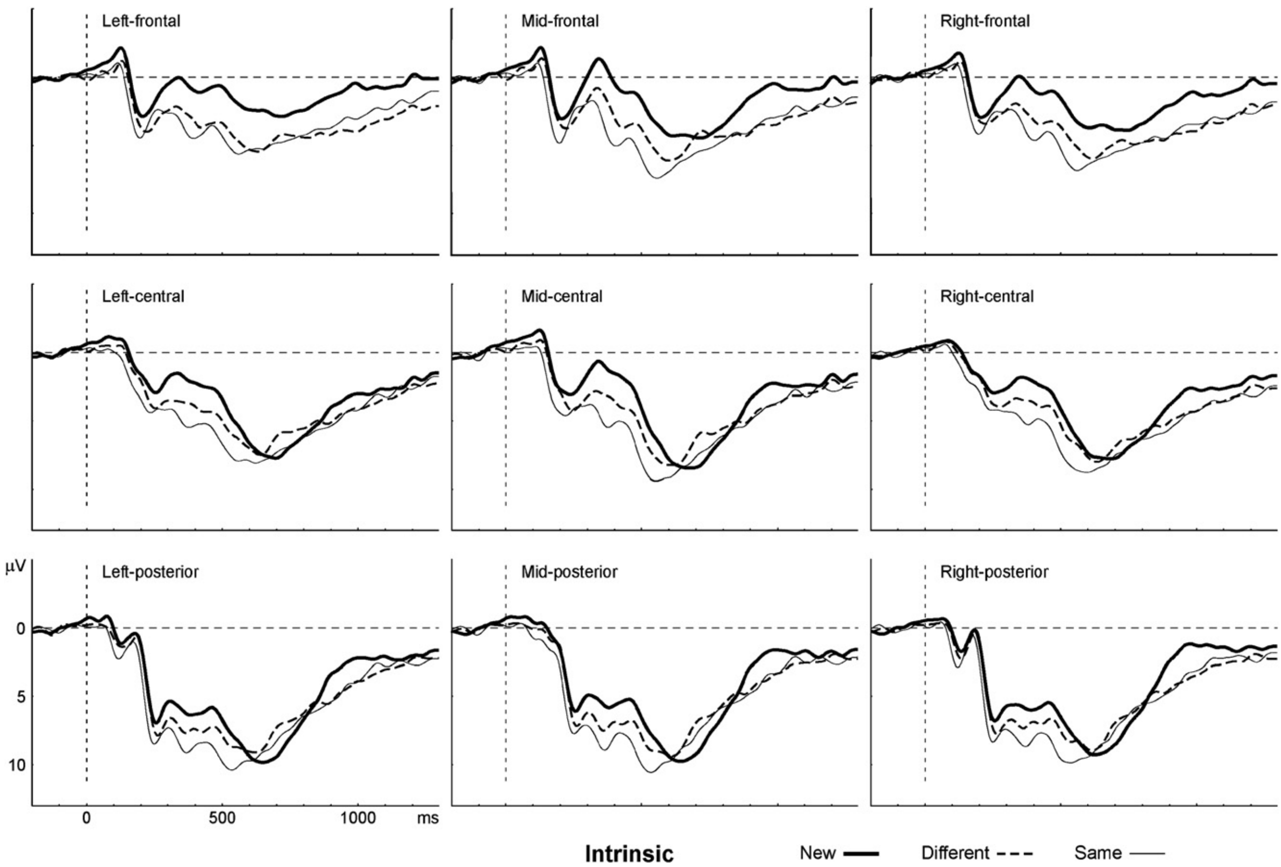

Fig. 4 – Topographically arranged (ROI) grand average ERP data from the Intrinsic condition; time scaling ranges from −200 to 1300 ms post stimulus onset; positive deflections are displayed downward.

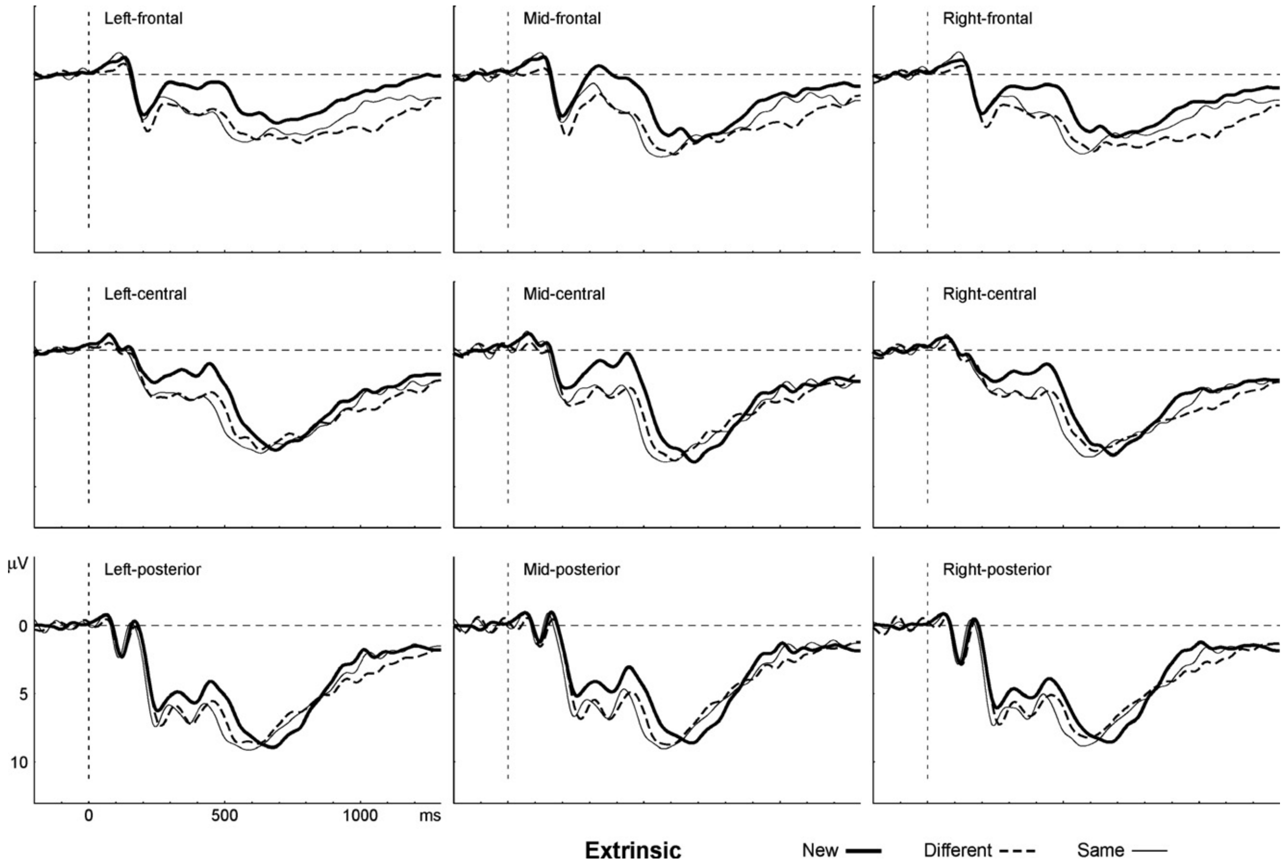

Fig. 5 – Topographically arranged (ROI) grand average ERP data from the Extrinsic condition.

all $F(1,31)<2.80$, all $p>0.10$. The insert in Fig. 6 shows the difference of difference waves, demonstrating that congruency effects differ between Intrinsic/Extrinsic conditions especially at (mid-)frontal sites. Note that this is partly due to the Extrinsic congruency effect showing a slight tendency to be larger at posterior sites.[2] Furthermore, a Condition (Old–New vs. Same–Different) by AP by Lat analysis yielded no interactions involving the Condition factor (all $F<1.9$, $p>0.1$). To avoid Type II error, an additional analysis was carried out with data from all 58 head electrodes. The respective Condition (Old–New vs. Same–Different) by electrode repeated measures ANOVA (applying the Greenhouse–Geisser procedure) yielded a significant Condition by Electrode interaction, $F(57,1767)=2.63$, $\varepsilon=0.09$, $p<0.05$, but this interaction did not prove reliable in an analysis of vector-scaled data, $F(57,1767)=1.48$, $\varepsilon=0.09$, $p=0.20$ (McCarthy and Wood, 1985; see also Dien and Santuzzi, 2005; Urbach and Kutas, 2002; Wilding, 2006).[3] Therefore, while we are aware of the limitations of the current data set, we feel safe to conclude that the congruency effect in the Intrinsic case modulates familiarity processing, especially given that this replicates previous research (Ecker et al., 2007b).

In Time window 2 (500–700 ms), an AP by Lat by Intrinsic/Extrinsic by Condition (New/Same/Different) analysis yielded only an AP by Condition interaction, $F(4,28)=8.35$, $p<0.001$, due to the fact that there were basically no old–new effects whatsoever at posterior sites.

Others have reported a lack of posterior recollection-related effects while finding such effects at frontal sites in later time windows (Senkfor and Van Petten, 1998; Van Petten et al., 2000). So finally, data of the 900–1200 ms period (Time window 3) were inspected, where there seemed to be old–new effects at frontal recording sites. A Condition (New/Same/Different) by Intrinsic/Extrinsic by AP by Lat analysis yielded an AP by Condition interaction, $F(4,28)=7.14$, $p<0.001$. Planned comparisons showed that only New and Different conditions differed consistently across Intrinsic/Extrinsic conditions at frontal ROIs. Same and Different waveforms differed only in the Extrinsic condition at both lateral frontal ROIs (see Table 2 for contrasts).

3. Discussion

The aim of this experiment was to investigate whether the manipulation of a perceptual feature would impact on recognition memory performance, and in particular whether it would impact differentially on ERP measures of familiarity and recollection, depending on its intrinsic versus extrinsic status. Therefore, we designed an experiment manipulating

[2] Whether or not this may reflect some early recollective processing in the Extrinsic case remains a highly speculative question, although this would be in line with our hypotheses.

[3] Although we still consider vector scaling a valid method (cf. Wilding, 2006), given the controversy regarding its use, the result was confirmed with an analysis on max/min scaled data, $F(57,1767)=1.57$, $\varepsilon=0.09$, $p=0.17$.

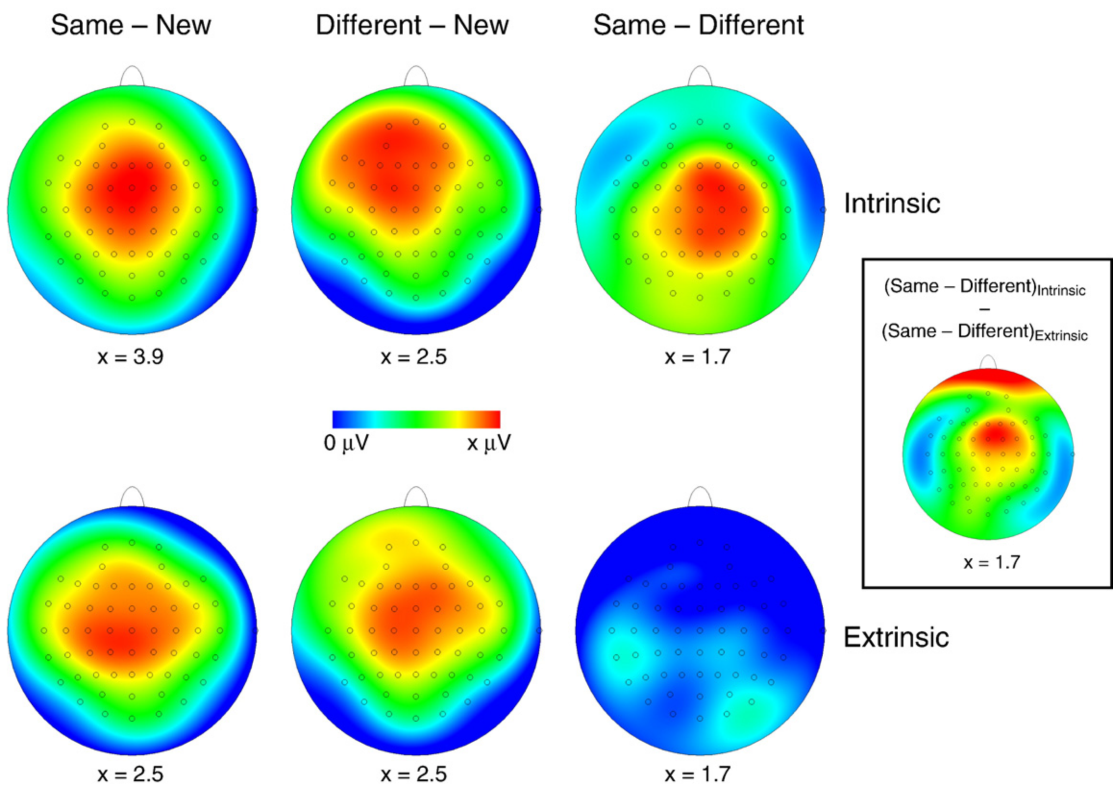

Fig. 6 – Spherical-spline interpolated ERP scalp maps of old–new effects (separately for Same and Different conditions) and congruency (Same–Different) effects in Time window 1 (300–500 ms) across Intrinsic and Extrinsic conditions. The insert depicts the subtraction of congruency effects (Intrinsic–Extrinsic).

the same feature – color – in an intrinsic and an extrinsic condition, holding constant all other factors, even including the number of color pixels in the two conditions.

As expected, performance in both Intrinsic and Extrinsic conditions was worse when color was changed from study to test. Given the task-relevance of the feature at both study and test, this is best explained by the partial mismatch between perceptual and mnemonic representations. In the Different condition, there was thus a conflict between matching item information calling for an "old" response and mismatching color information. New items, on the other hand, could be rejected based on item information alone and responses were therefore fastest. Interestingly, overall hit responses were slower in the Extrinsic condition, suggesting that the integration of extrinsic color information is slower and likely less automatic than intrinsic integration.

Table 1 – Planned comparisons concerning Intrinsic and Extrinsic conditions at the mid-frontal ROI in Time window 1

Contrast	*df*	*F*	*p*
Intrinsic condition			
New–Same	1,31	49.37	<0.0001
New–Different	1,31	19.46	0.0001
Same– Different	1,31	11.68	0.0018
Extrinsic condition			
New–Same	1,31	29.48	<0.0001
New–Different	1,31	34.66	<0.0001
Same–Different	1,31	<1	

Turning to ERPs, the results concerning the FN400 old–new effect associated with familiarity were clear-cut. Changing an intrinsic object feature from study to test diminished the FN400 old–new effect, whereas the extrinsic manipulation had no effect whatsoever. Thus, presumably, intrinsic color is part of the representation used to assess object familiarity, whereas extrinsic color is not. This offers an explanation for the behavioral result pattern, that is, extrinsic feature integration is slower because it cannot be based on familiarity processing. In other words, because subjects' decision needed to take color into account, reactions were quicker in the Intrinsic case because subjects could use the early familiarity signal as a first indication of Same/Different status. Given the quite high latencies, subjects apparently did not base their decisions on the rather equivocal familiarity signal alone. Yet, the familiarity signal may have influenced further (recollective) processing, thus accelerating responses in the Intrinsic condition.

We had recently reported a similar FN400 pattern in an inclusion task, for which the intrinsic color information was thus not relevant for the decision, in contrast to the present case (Ecker et al., 2007b). Therefore, it can now be concluded that familiarity can be perceptually specific across a range of tasks tapping recognition memory, and this effect seems independent of task relevance. The data from our laboratory (see also Groh-Bordin et al., 2005, 2006) suggests that, given item processing is not purely conceptual (e.g., due to task demands), perceptual features are included in the representation subserving familiarity memory as long as they are integral to the object. The present experiment shows that it is

Table 2 – Planned comparisons concerning Intrinsic and Extrinsic conditions at frontal ROIs in Time window 3

Contrast	*df*	*F*	*p*
Intrinsic condition — left-frontal ROI			
New–Same	1,31	3.90	0.06
New–Different	1,31	7.73	0.0092
Same–Different	1,31	2.91	0.10
Extrinsic condition — left-frontal ROI			
New–Same	1,31	2.68	>0.1
New–Different	1,31	16.12	0.0004
Same–Different	1,31	8.31	0.0071
Intrinsic condition — mid-frontal ROI			
New–Same	1,31	4.08	0.05
New–Different	1,31	4.66	0.0387
Same–Different	1,31	<1	
Extrinsic condition — mid-frontal ROI			
New–Same	1,31	<1	
New–Different	1,31	8.24	0.0073
Same–Different	1,31	5.92	0.0209
Intrinsic condition — right-frontal ROI			
New–Same	1,31	5.89	0.0212
New–Different	1,31	7.68	0.0093
Same–Different	1,31	1.04	>0.1
Extrinsic condition — right-frontal ROI			
New–Same	1,31	1.77	>0.1
New–Different	1,31	15.86	0.0004
Same–Different	1,31	8.37	0.0069

truly the intrinsic/extrinsic factor determining whether or not feature manipulations will impact on familiarity, as all other factors were held constant; most importantly, the same feature was manipulated in both conditions. This is to our knowledge the first ERP study to disentangle these two factors. Thus, the present results make a stronger argument for the assumption that *belongingness to the object* is a relevant and constituent factor of familiarity processing. It should be noted that the intrinsic–extrinsic dimension may not only differ in the respective binding mechanisms, although we consider this to be a major difference. Rather, everything intrinsic belongs to the object and thus necessarily modulates phenomenal object experience more than any extrinsic information. For instance, reduced object familiarity by intrinsic manipulation could also be framed as enhanced novelty and could thus be associated with surprise, reevaluation, or reconciliation. Yet, given previous research, these evaluative processes are very likely to occur at later processing stages (Czernochowski et al., 2005; Wilding and Rugg, 1997).

There are also reported null effects of perceptual manipulations on familiarity ERP effects (Curran, 2000; Curran and Cleary, 2003). Yet, these studies had implemented only rather small changes (e.g., adding a plural -s to a word) that were perhaps therefore not picked up by the rather coarse familiarity estimate (Holdstock et al., 2002; Mayes et al., 2002). Furthermore, because in the present case coloring was arbitrary and did not affect semantic appropriateness, the present results contradict an alternative conceptual priming account of the early mid-frontal old–new effect (Yovel and Paller, 2004; Voss and Paller, 2006), although importantly, this is not to say that familiarity does not entail any conceptual processing (see also Curran et al., 2002; Groh-Bordin et al., 2006).

As far as recollection is concerned, hypotheses were that the feature manipulation should impact on the LPC effect in both conditions. Yet, no LPC effects were found in the current study. One interpretation of this null effect is that subjects simply did not exert significant amounts of recollection and based their judgments on relative familiarity. For instance, Kelley et al. (1989) reported an old–new recognition advantage for same vs. different modality repetitions of words and argued this was based on familiarity (although they have a different conception of familiarity, discussing perceptual fluency as its basis). Yet, if this interpretation is correct, then ERPs in this case were seemingly not sensitive enough to pick up physiological catalysts of present behavioral effects (i.e., the RT congruency effects in the Extrinsic group). Nevertheless, given that recollection is considered a flexible and controllable process (Bergström et al., 2007; Ecker et al., 2007b; Herron and Rugg, 2003; Wilding et al., 2005), the "no recollection" interpretation is still a feasible one. Herron and Rugg (2003) emphasized that successful exclusion of (studied or new) nontargets in an exclusion task does not necessarily require recollection, because a lack of recollection can be used to determine the status of nontargets. Wilding et al. (2005) extended this finding and demonstrated that subjects can flexibly adjust their use of recollection (of nontarget information), despite largely overlapping target and nontarget information (see also Fraser et al., 2007). Yet, all of these studies also consistently reported a reliable LPC effect for targets across experiments, unlike in the present case. In the Intrinsic condition of the current experiment, subjects may well have based their judgments on relative familiarity (in line with the graded FN400 effect) and this may explain the lack of an LPC effect. However, ERPs of the Extrinsic condition suggest that relative familiarity was of comparable magnitude for Same and Different test items. It therefore seems as if the behavioral congruency effects cannot be based on different levels of familiarity. Rather, the pattern of behavioral congruency effects on the one hand and no FN400 congruency effects on the other seems to suggest that behavioral effects are in fact based on a process other than familiarity — whether or not this process is adequately described as recollection. The question remains why this process is not directly apparent in test ERPs.

Two source memory studies of Van Petten and Senkfor (Senkfor and Van Petten, 1998; Van Petten et al., 2000) have also diverged from other findings in that they did not report a pronounced parietal recollection LPC effect. Instead, they found more frontal effects in later time windows (800–1200 and 700–1100 ms, respectively) and suggested that these were indexing processes of context search or retrieval evaluation, monitored by the prefrontal cortex. They argued that item and source memory constitute two successive and hierarchical processes. Given that prefrontal control processes can be seen as an integral part of recollective processing (Herron and Rugg, 2003), we agree with this proposition. In line with the results of the Van Petten and Senkfor studies, Time window 3 data show that there is at least some differential processing of Same and Different test items between 900 and 1200 ms at frontal sites, especially in the Extrinsic condition, so these effects may reflect control or evaluation processes associated with feature integration and may thus be a correlate of the behavioral congruency effects in the Extrinsic condition, although their onset may be too late to fully account for the behavioral effects.

An alternative and perhaps complementary interpretation rests on the assumption that there may have been differential processing of Same and Different items in the Extrinsic condition occurring after familiarity calculation, but that these effects were occluded in the grand average data because of an LPC effect inversion (positive shift for CRs) in a substantial subset of participants, as suggested by visual inspection of single subject data.[4] Whether this inversion could be due to an overlapping LPN component associated with continued and extended integration processing (cf. Johansson and Mecklinger, 2003) or a positive shift associated with target-like processing of new items (cf. Azimian-Faridani and Wilding, 2006; Nessler et al., 2004) – suggesting a strategy difference across subgroups of participants – remains speculative and awaits further research.

4. Experimental procedures

4.1. *Materials and design*

Stimuli were line drawings of everyday objects. Each item existed in two versions, as a fully colored silhouette (with black outlines; intrinsic condition) and a black line drawing encased with a colored rectangular frame (extrinsic condition). There were six different colors: green, red, magenta, turquoise, dark blue, and yellow; every specific object existed in two color versions (i.e., actually there were 4 versions of each object — Intrinsic/Extrinsic–color1/color2). The frame in the extrinsic version contained the same number of color pixels as the fully colored version of the respective line drawing, so physically, the amount of color information was identical (see Fig. 1 for details).

Subjects studied 144 stimuli (half intrinsic, half extrinsic) on the white background of a computer screen for 2500 ms each. Instructions were to memorize the object and its color (or the color of the frame, respectively). At test, subjects were presented with all old items intermixed with 72 new items (half intrinsic, half extrinsic). The color of half the old items was changed between study and test (Different condition), the other half was presented identically (i.e., no color change; Same condition). Subjects made a threefold decision (same/different/new) with instructions to respond as quickly and as accurately as possible.

First and second presentation colors as well as their transitions were counterbalanced within each subject. That is, seeing a green object was as likely as seeing a yellow one, and the transition from red to blue in a Different study–test case was as likely as a transition from red to green, or any other combination. Most objects had no specific prototypical color; yet, to preclude an influence of pre-existing semantic knowledge, both color versions of a specific object were designed to match in terms of semantic appropriateness, although no formal testing was carried out (e.g., a chili pepper may have existed in red and green, or in turquoise and dark blue). For their response, subjects used three keys of a standard keyboard; there were four different combinations of keys used and this was counterbalanced across subjects to avoid undue EEG lateralization effects. Keys were A, X, and 2, 6 (of the number block); for each combination, Same and Different conditions were assigned to two keys on the same side of the keyboard (i.e., 2 and 6 or A and X), while the new condition was assigned to the other side (e.g., X or 2).

The two types of items (intrinsic, extrinsic) were presented blockwise, and there were four study–test blocks. The intrinsic–extrinsic sequence of conditions was counterbalanced across subjects. That is, one group of subjects was given two Intrinsic study–test blocks and then proceeded to the two Extrinsic study–test blocks, or vice versa (there were only sequences of the AABB type). Every specific item was presented twice (at random interval) during its respective study block to enhance performance. The actual experiment was preceded by a practice phase, in which subjects first internalized key assignments and then practiced the task with three items (of the intrinsic/extrinsic style as according to their starting condition) not used in the experiment proper. After completion of the first two blocks, there was another practice phase with three items of the intrinsic/extrinsic style not yet encountered by the specific subject. Thirty-two right-handed subjects took part in this experiment and were paid for their effort. Subjects were non-psychology students at Saarland University (mean age 23.9, range 20–39, 17 subjects were female).

4.2. *EEG/ERP methods*

The EEG was recorded from 63 Ag/AgCl electrodes arranged according to the extended international 10–20 system (Easycap GmbH, Herrsching-Breitbrunn, Germany). Sampling rate was 250 Hz, and signals were amplified with an AC coupled amplifier (Brain Amp MR, Brain Products, Munich; time constant 10 seconds, analog low-pass filter 70 Hz, notch filter 50 Hz). A left mastoid reference was used, but signals were re-referenced offline to averaged mastoids. EOG artifacts picked up by four ocular electrodes (two above and below the right eye, and two further electrodes at the outer canthi of both eyes) were corrected offline (Gratton et al., 1983). Before averaging, trials containing artifacts (lowest activity in successive 100 ms intervals ±0.5 μV, maximum amplitude in the segment ±150 μV, maximum voltage step between two successive sampling points 50 μV, maximum difference between any two sampling points within an epoch 150 μV) were excluded (5.2% of trials). Digital bandpass filtering was applied between 0.2 and 20 Hz. ERPs were calculated by time-locked signal averaging, using the time window from −200 to 1300 ms relative to stimulus onset. Analysis was based on trials with correct responses, resulting in the following mean trial numbers per condition: Intrinsic-New/Same/Different (33/29/27), Extrinsic-New/Same/Different (32/28/26). The minimum number of trials per condition included in a grand average was 16. Following suggestions by Dien and Santuzzi (2005), statistical analyses were performed by means of MANOVAs on mean voltages in several different time windows (for details see the Results section). ROIs were formed by

[4] An online supplement with a comprehensive post-hoc analysis comparing groups with standard vs. inverted LPC effect is available at http://psydok.sulb.uni-saarland.de/volltexte/2007/988/, or from the corresponding author. Notably, the FN400 effect pattern across Intrinsic and Extrinsic conditions was uninfluenced by this LPC grouping factor.

averaging signals from the following electrodes: left-frontal: AF3, F3, F5; mid-frontal: FCz, F1, F2; left-central: C3, C5, CP5; mid-central: CPz, C1, C2; left-posterior: P3, P5, PO3; mid-posterior: POz, P1, P2; and the respective right counterparts to left-sided regions and electrodes. Analyses were followed up by planned comparisons, applying Holm's sequential Bonferroni correction of alpha levels where applicable (Holm, 1979).

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