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Content dependence of the neural correlates of recollection: ERP old/new effects for faces, objects and words.

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Abstract

As previous research on content-specificity of the neural correlates of recollection is inconclusive, event-related potentials were used to assess old/new effects for faces, objects and words. The data demonstrate temporal differences in ERP old/new effects as a function of item type, supporting the notion that material-dependent processes underlie recollection-related neural activity. The results are discussed in terms of how nameable and non-nameable material elicit different neural representations of mnemonic information, as a consequence of how different item types are encoded and retrieved according to perceptual and contextual content.

Keywords: Recognition memory, event-related potentials, material specificity, old/new effects, recollection

Introduction

The most fundamental function of episodic memory is the online recovery of past events into consciousness, a characteristic of the human mind that is essential for many aspects of our nature. The processes associated with reinstatement of an episode takes place when a retrieval cue reactivates the memories associated with that cue, and the event is brought back to life.

Extensive research on the neural and functional characteristics of episodic memory retrieval has led to assumptions that recognition judgments are supported by two distinct memory processes, recollection and familiarity (Mandler, 1980). Recollection involves recovery of qualitative information such as contextual details about the encoding of an episode, whereas familiarity can be compared with the feeling of recognition without memory of where and when the episode was encountered (Addante, Ranganath & Yonelinas 2012; Yonelinas, 2002).

The two memory processes have been studied using electrophysiological recordings of brain activity, demonstrating differences in event-related potentials (ERPs) between stimuli correctly endorsed as old versus stimuli correctly endorsed as new. These differences in waveforms across old and new stimuli offer neural indices of successful memory retrieval and two distinct ERP old/new effects have been associated with familiarity and recollection respectively. The *mid-frontal old/new effect,* evident between 300-500 ms post-stimulus and maximal over mid-frontal sites, accompanies recognition of old items in the absence of recollection of contextual details and is held as a generic index of familiarity, whereas a later *parietal old/new effect,* evident in the 500-800 ms epoch post-stimulus and maximal over parietal electrodes with a left lateralization, is associated with recognition of old items together with contextual information about the previous episode and held as a generic index of successful recollection (Curran, 2000, Duarte, Ranganath, Winward, Hayward & Knight; 2004, Ranganath & Paller, 2000; Schloerscheidt & Rugg, 1997; see Wilding & Ranganath, 2011, for review). Familiarity and recollection are both believed to operate independently of modality or domain of information, and consistent with this view many studies have shown dissociation between the neural correlates of these two processes across different materials and different encoding tasks (Addante et al., 2012; Anderson et al., 2011; Hongkeun & Cabeza, 2009; Johnson, Suzuki & Rugg, 2013; Ranganath et al., 2003).

In contrast to an extensive research on the generic indices of recognition memory, the content- specific properties of ERP correlates of memory are in its early investigation. Episodic memory retrieval, or recollection, is believed to involve the reinstatement of cortical activity engaged during encoding. The reinstatement hypothesis holds that recollection takes place when a retrieval cue reactivates the distributed pattern of cortical activity that characterized the encoding of the episode. The representation of that pattern of neural activity is indexed by the hippocampus and through connections between hippocampus and cortical regions a retrieval cue activates the reinstatement of the same neural activity as during encoding, which allows recollection of the episode (Danker & Anderson, 2010; Johnson et al., 2013; Kahn, Davachi & Wagner, 2004; Woodruff, Johnson, Uncapher & Rugg, 2005). Consistent with this view, several studies have shown that different types of information recollected, as well as same type of stimuli processed differently during encoding, elicit distinct neural activity (Awapi & Davaci 2008; Galli & Otten, 2011; Hofstetter & Vuilleumier, 2012; Jonhson & Rugg, 2007; Johnson, Minton & Rugg 2008; Khader et al., 2007; MacKenzie & Donaldson, 2009; Woodruff et al., 2005; Yick & Wilding, 2008). For instance, a double dissociation have been demonstrated within left fusiform cortex where recollected words elicits greater activity in lateral fusiform compared to pictures, in conjunction with the opposite pattern in anterior fusiform (Johnson & Rugg, 2007; Woodruff et al 2005).

Furthermore, such findings have supported theories of two different neural operations supporting episodic memory retrieval, such that recollection of an event seems to depend on material-independent neural activity, held as a 'core recollection network', in operation together with material-dependent processes, (Johnson & Rugg 2007; Johnson et al 2013). In a more recent study by Johnson and colleagues (2013), regions associated with material-independent recollection-related activity and regions related to content-specific activity were compared in a recognition task. Besides activity in medial-temporal regions and prefrontal cortex, generally associated with recollection, the results revealed an overlapping activity across encoding and retrieval in brain regions characterized by reflecting material-specific processing. These results provide further support for the notion that episodic memory retrieval is supported by two cognitive processes, where a content- specific reinstatement of cortical activity operates conjointly with a more general process of memory retrieval (Johnson et al 2013; Johnson & Rugg 2007).

Research using the method of functional magnetic resonance imaging (fMRI) is further supported by studies using ERPs to investigate the content-specific features of the neural correlates of episodic retrieval (Galli & Otten, 2011; Johnson et al., 2008; MacKenzie & Donaldson, 2009; Yick & Wilding, 2008). As fMRI has a good spatial resolution allowing an analysis of activity in specific brain regions, ERPs have a higher temporal resolution offering an important complement to establish when in the process of memory retrieval material-specific processes occur. As predicted by the reinstatement hypothesis, content-specific activity reflects the reinstatement of processes engaged during encoding. Consequently, content-specific processes should be necessary for successful memory retrieval and hence occur relatively early in the process of recollection, at least as early as any generic indices of recollection. To test whether material-specific effects manifests online recovery of episodic information or merely reflects post-retrieval processing, two studies manipulated the to-be-remembered information and examined the consequences on the left parietal old/new effect, identified as the putative neural index of recollection (Johnson et al., 2008; Yick & Wilding, 2008).

Johnson and colleagues (2008) demonstrated content-specific effects for recollected words, where the effects differed according to previous encoding. Participants either integrated the word in a sentence or imagined the object represented by the word. An anterior old/new effect was evident 300 ms after stimulus onset and was more positive-going for words encoded in a sentence generation task than words encoded in a scene. Johnson and colleges (2008) interpreted the anterior old/new effect as manifesting qualitative differences in the characteristics of the retrieved information and, more importantly, the effect occurred somewhat earlier than the left parietal old/new effect which supports its essential role in successful retrieval. Moreover, the effect persisted for almost a second and later shifted in topographical distribution, from a left to a right lateralized maximum. This shift in scalp distribution was argued to reflect a summation of content-specific processes and post-retrieval operations (Johnson et al., 2008).

Also, Yick and Wilding (2008) presented similar results using words and faces, where content-specific effects for faces showed an anterior scalp distribution between 500-800 ms. Yick and Wilding (2008) point out that the material-specific anterior old/new effect found for faces not necessarily is specific to faces alone. It may just as well reflect the reinstatement of spatial information or information associated with forms and configurations (i.e. characteristics a face share with other types of stimuli, such as scenes and pictures of objects).

These findings have been extended further in a study comparing words, faces and objects in both blocked and randomized study-test compositions (Galli & Otten, 2011). A material-specific anterior old/new effect was evident for faces and objects in the 300-500 ms epoch, when stimuli type were randomized as well as blocked, whereas during the later time window of 500-700 ms, the effect was observed only when stimulus type was blocked. Words showed a more posterior distribution in the early epoch. As Galli and Otten (2011) argue, together these findings points towards a direct role of material-specific operations in searching for and reinstatement of stored information in memory, such that the material-dependent effect onsets in the 300-500 ms epoch, persisting through the 500-700 ms time-window. This strongly supports the notion of its representation of online recovery of specific episodic content. Furthermore, the material-specific processes supporting recollection, seems to mainly operate on the difference between visual and verbal information, such that the more frontal old/new effect for visual material reflects the recovery and reinstatement of perceptual processing, hence the spatial distinction between objects and faces compared to words (Galli & Otten, 2011).

Another study of interest compared ERPs elicited by either names or faces as retrieval cues for faces associated with names during encoding (MacKenzie & Donaldsson, 2009). Consistently, an anteriorly distributed old/new effect (500-700 ms) was evident for faces, whereas names were associated with the typical mid-frontal and left parietal old/new effects. In contrast to the view of content-specific activity reflecting the reinstatement of episodic content, MacKenzie and Donaldsson (2009) argue that the anterior old/new effect for faces is instead sensitive to the recovery and reinstatement of the context associated with encoding. Seeing that the encoding is similar across trials, involving the same type of stimuli, with only the retrieval cues differing suggests that the anterior old/new effect reflects the reinstatement of context rather than content.

Thus, content-specific recollection-related neural activity occurs well in time to support the reinstatement hypothesis and material-specific effects are clearly involved early in the retrieval process, indicating an essential role for successful recollection. However, the nature and function of these content-specific effects, particularly the anterior old/new effect, is uncertain according to the findings presented above. The effect may reflect online recovery of an episode, but it might also represent online recovery of certain features of the episode, such as representations of visuo-perceptual attributes, as well as the context associated with encoding. Material-specific effects seem to represent processes supported by different features of the episode to-be-recollected, critically verbal versus visual information, linking both faces and pictures of objects to the same anterior effect (Galli & Otten, 2011; Yick & Wilding, 2008). This view, however, is challenged by the fact that the anterior old/new effect has been related to verbal stimuli as well (Johnson et al., 2008).

As the previous research on the content-specific nature of the ERP old/new effects associated with recollection is inconclusive, the aim of the present study is to shed light on the ERP effects for different types of stimuli. Essential to the issue is a further investigation of what features of an episode evoke different neural correlates of episodic retrieval and, more precisely, the spatio-temporal differences in ERPs between stimulus types. In line with previous research we expected an early anterior old/new effect followed by a later posterior old/new effect for recollected stimuli. We also expected spatio-temporal differences between different stimulus types and in contrast to earlier studies (Galli & Otten, 20011) we expected differences in ERP old/new effects between objects and faces as well. The anterior material-specific effect evident for faces and objects might reflect a distinction between processing of verbal and visual features, as argued previously, but we want to emphasize the fact that nameable objects have a verbal dimension that should be just as relevant for memory retrieval as the visual dimension, whereas there are reasons to believe that underlying neural processes differs between retrieval of objects and faces.

To further examine the content-specific characteristics of processes supporting recollection, ERPs elicited by correctly remembered old (hits) and correctly rejected new (correct rejections) items for faces, objects, and words were compared in an old/new recognition task to assess ERP memory effects for each stimulus type respectively. Moreover, subjects rated how confident they were in their judgments. This allowed us to assess if stimulus type influenced the strength of the resulting memory, as reflected in the proportion of high-confidence correct responses (Dunn, 2004).

Methods

Participants

Sixteen right-handed, healthy adults, (mean age = 25,4 years, range 19-31, 9 males) volunteered to participate in the experiment. Each participant was native Swedish speaking and they gave written informed consent and were compensated with a movie ticket for their participation.

Materials

The stimulus material consisted of 120 words, 120 objects and 120 faces. All words were Swedish nouns 4-6 letters long (mean length = 4.9 letters; mean written frequency = 15.9 /million; Språkbanken) and divided into two sets equal in word length and written frequency. Pictures of faces were retrieved from a database used in an ERP study of appraisal of facial beauty (Schacht, Werheid, & Sommer, 2008). The faces were color pictures of young adults, shown with hair, neck and small part of the shoulders. The faces included no distinct features such as glasses, mustaches or jewelries and had neutral facial expressions. The faces were divided into two sets for counter-balancing purposes, which were comparable in level of attractiveness and number of males and females (Schacht et al., 2008).

Objects were color pictures of nameable objects from different categories, collected from the Amsterdam Library of Object Images (ALOI) (retrieved from http://staff.science.uva.nl/~aloi/) (Geusebroek, Burghoufs & Smeulders, 2005). Words and pictures of objects were controlled for to not represent the same object to minimize inter-stimuli overlap, so that for instance the word tomato and a picture of a tomato would not both occur in the recognition test (see Appendix for lists of words and objects).

The words were written in lowercase arial font size 40, and were presented in white color on black background. The size of the pictures was 700 × 600 pixels on a 27” computer screen with a 2560 × 1440 resolution. Stimuli in both study and test were centrally displayed on a black background. Each test phase begun with three filler trials that were later excluded from the analysis.

Design and procedure

After giving informed consent, the participants were seated in front of the experiment computer and were fitted with an electrode cap. (See EEG/ERP acquisitions for details about the EEG recording procedure.) Oral instructions were given prior to the experiment and written instructions were given on the screen before each study and test phase, where participants were told to first rate and encode items presented on the screen and later recognize the previously studied items presented intermingled with new items.

The experiment consisted of a total number of 540 trials divided into six study-test blocks. Each study phase contained 30 items with 10 from each stimuli category and each item was shown for 3000 ms followed by a white fixation cross, shown for 489 ms, where participants were instructed to respond whether they liked, disliked or were neutral to the item presented on the screen. Participant responded by using left index finger, middle finger and ring finger to press a button on a response box corresponding to one of the response alternatives respectively. The liking rating task was used to achieve a relatively deep encoding and facilitate recognition based on recollection. After the study phase, subjects were immediately tested for memory performance.

The test phases consisted of the 30 items from the study phase plus 30 additional new items, 10 from each stimuli category. During test, items were shown for a relatively short duration, 289 ms, to avoid eye movements. Test probes were followed by a white fixation cross shown for 2684 ms where participants had been instructed to make their old/new response as quickly and accurately as possible using right index finger and middle finger pressing a button on the response box corresponding to the response alternatives. The mapping between response alternative and response finger was counterbalanced across subjects. As soon as an old/new response were given, instructions were shown on the screen asking participants to make a confidence rating of how confident they were about their old/new judgment for each trial. For confidence responses, participants were instructed to use left ring finger, middle finger and index finger pressing a button on the response box, each button corresponding to either *Confident, Quite Confident* or *Uncertain* (In Swedish; helt säker, ganska säker, osäker). After participants made their confidence rating, a new trial started immediately.

To minimize the influence of item-specific effects, the allocation of stimulus set to old-new status and experimental block was counterbalanced across subjects to make sure that each item was equally often old and new and evenly distributed across the blocks of the experiment. The presentation order during study and test phases was pseudorandomized with the constraint of a maximum of three consecutive items from the same category and old-new status.

EEG/ERP acquisition and analysis

Each participant was fitted with an electrode cap (EASYCAP, Herrsching-Breitbrunn, Germany; www.easycap.de) EEG data were recorded from 32 scalp sites with 32 silver/silver-chloride ring electrodes located at the scalp according to the 10% system (see montage no 24 at http://www.easycap.de/easycap/e/products/products.htm#15). Electrodes FT9, FT10, TP9 and TP10 were excluded from the recording. A ground electrode was adhered to the cap at the location corresponding to AFz. Two additional electrodes were attached to the reference sites on the left and right mastoid, the left mastoid served as the active reference during recording.

Electrooculogram (EOG) was recorded from electrodes adhered to the temple outside the outer canthus of both eyes and below and above the left eye. These channels were re-referenced offline to form bipolar vertical and horizontal EOG channels. All channels were digitized with 32-bit resolution at a sample rate of 500 Hz and amplified from DC to 200 Hz on a Neuroscan NuAmps system. Prior to recording, each electrode was adjusted so that the impedance was below 5k Ohm for the scalp electrodes, below 3k Ohm for mastoids and below 10k Ohm for EOG electrodes.

Data Analysis

The electrode sites IZ, P09 and P10 were later excluded from the data analysis due to artifact contamination of the EEG data.

Off-line, the data were digitally filtered between 0.1 and 30 Hz (48 dB roll-off, zero phase shift filter) and re-referenced to linked mastoids. The continuous EEG was segmented into epochs beginning 200 ms prior to stimulus presentation and ending 1000 ms poststimulus presentation. The ERPs were baseline corrected using the prestimulus interval. EOG artifacts were corrected using Independent Component Analysis (in EEGLAB) (Delorme & Makeig, 2004). Epochs containing recording-related artifacts (±75μV) were rejected prior to averaging. ERP averages were formed seperately for correctly judged old and new faces, objects and words (with a minimum of 15 accepted trials per condition and participant).

Results

Behavioral data

Reaction times and probability values are shown in Table 1, demonstrating the overall high performance on the memory test.

A repeated measures ANOVA using the factors Item Type (face, object, word) and Item Status (old, new) showed no significant differences in RT to hits and correct rejections across item categories. The mean probabilities for correct responses to old items (hits) were 0.84 for faces, 0.94 for objects and 0.91 for words.

Table 1. Measures of Memory Performance and Response Times

	Faces	***Objects***	***Words***
Proportion			
Hits	0.84 (0.08)	0.94 (0.05)	0.91 (0.06)
False alarms	0.27 (0.19)	0.07 (0.06)	0.09 (0.08)
Misses	0.16 (0.16)	0.06 (0.05)	0.09 (0.06)
Correct rejections	0.73 (0.19)	0.93 (0.06)	0.91 (0.08)
Response Time (ms)			
Hits	1248 (54)	1230 (36)	1248 (40)
False alarms	1277 (133)	1225 (178)	1302 (222)
Misses	1198 (130)	1184 (446)	1252 (136)
Correct rejections	1234 (63)	1242 (39)	1253 (48)

The average proportion values are calculated in relation to the total number of old and new items in each category. Standard deviations are shown i parantheses.

The assessment of task performance was based on the Two-High Threshold Model, which assumes two discrete memory states, recognition or non-recognition, measured with discrimination index (Pr) and response bias index (Br) (Snodgrass & Corwin, 1988). The mean value of old/new discrimination [Pr = (Hit–False alarm)] and standard deviation was 0.57 (*SD* = 0.18) for faces, which differed from objects and words for which discrimination values were 0.87 (*SD* = 0.10) and 0.82 (*SD* = 0.12) respectively. An ANOVA confirmed that there was a main effect of stimuli type on old/new discrimination (accuracy) [F (2, 30) = 37.458, $p < 0.001$] where follow-up pairwise comparisons showed that the mean value for faces was significant lower compared to words and objects, indicating poorer accuracy for faces. Response bias, defined as Br = [(False alarm)/(1-Pr)] measures the probability of an "old" response when the participant is uncertain about the item status (Snodgrass & Corwin, 1988). Our results yielded Br values of 0.56 (0.25) for faces, 0.54 (0.21) for objects and 0.50 (0.17) for words, which indicates a neutral response bias for words, and slightly liberal response bias for objects and faces. (Feenan & Snodgrass, 1990) Repeated measures ANOVAs were performed to test differences in response bias across item types and no significant effects of stimuli type on memory performance were found. [F (2, 30) = 0.525, NS = not significant]

Confidence was used to assess memory strength and was measured as the proportion of high-confidence judgment ("Confident") of all correctly recognized items (hits). Average high-confidence values were 0.33 for faces, 0.36 for objects and 0.37 for words. An ANOVA using Item Type as a repeated measures factor showed no significant differences in confidence rating between stimuli categories, [F (2, 30) = 0.437, NS], indicating that memory judgments were based on recollection to the same amount across all stimuli categories.

ERP results

An initial repeated measures omnibus ANOVA was conducted on the amplitude differences in each time window between items correctly endorsed as old (Hits) and items correctly endorsed as new (Correct rejections) using factors of Item type (face, object, word), Item status (old, new), Location (anterior, posterior) and Hemisphere (left, mid, right). The analysis was performed on 20 electrodes (F7, F3, FZ, F4, F8, FC5, FC1, FCZ, FC2, FC6, T7, C3, CZ, C4, T8, P7, P3, PZ, P4 and P8) reflecting anterior – midline- posterior and left-midline- right electrode positions. Mean amplitudes were analyzed for three epochs (300-500 ms, 500-700 ms and 700-800 ms) in line with previous research and according to a visual inspection of were differences in old/new effects may be topographically, capturing the effects shown in Figure 1 and 2. Every interaction with item type was followed up with a separate ANOVA for each item type respectively, using factors Item Status (old/new), Location (anterior/posterior) and hemisphere (left to right). Grennhouse-Geisser correction was applied when violations of sphericity was evident. Uncorrected degrees of freedom are reported in the result together with corrected *p*-values.

300-500 ms epoch

The omnibus ANOVA demonstrated a significant main effect of Item Type [F (2, 30) = 20.899, p < 0.000] and a significant main effect of Item Status [F (1, 15) = 11.139, p < 0.004]. Moreover, the analysis provided a significant Item Type × Item Status interaction [F (2, 30) = 6.414, p < 0.004] showing differences in old/new effects over item types. As suggested by Figure 1, this was due to a generally greater old/new effects for objects. More importantly, a significant three-way Item type × Location × Hemisphere interaction [F (24, 360) = 13.816, p < 0.001] indicated differences in scalp distributions across item type.

Follow up analysis for each item category demonstrated an Item Status main effect [F (1, 15) = 17.306, p <0.001] for objects together with an Item Status × Location interaction [F (3, 45) = 7.807, p <0.010] and an Item Status × Hemisphere interaction F (4, 60) = 7.101, p <0.003], reflecting an anterior distribution of the old/new effect for objects in this early epoch with a mid-frontal maximum (see Figure 2).

There were no old/new effects evident for words (Maximum F >1, NS) or faces (Maximum F < 2, NS) in the early time window.

500-700 ms epoch

The omnibus ANOVA for the 500-700 epoch demonstrated an Item Type main effect [F (2, 30) = 20.871, p < 0.001], an Item Status main effect [F (1, 15) = 49.031, p < 0.001] and, more importantly, an Item Type × Item Status interaction effect [F (2, 30) = 8.127, p < 0.002] representing differences in old/new effects as a function of item type. Furthermore, an Item type × Location × Hemisphere interaction effect [F (24, 360) = 14.015, p < 0.001] demonstrates general differences as a function of item types.

Follow up ANOVA for the different stimuli categories confirmed an old/new effect for objects [F (1, 15) = 30.338, p < 0.001] and words [F (1, 15) = 7.902, p < 0.13] with no effect for faces (Maximum F > 2, NS). Interaction effects between Item Status × Location [F (3, 45) = 5.483, p <0.025] and Item Status × Hemisphere [F (4, 60) = 8.284, p <0.003] for objects reflects again an anterior distribution of the old/new effect for objects (see Figure 2).

There was no significant interaction between Item Status, Location and Hemisphere for words, suggesting a more widespread distribution of the old/new effect for words. To qualify the reliability of topographical differences between the old/new effects for objects and words an ANOVA using the whole set of electrodes (28) were employed. Importantly, an Item Type × Item Status × Electrode interaction [F (27, 405) = 4.318, p <0.011] was evident, reflecting the more anterior effect for objects and the more posterior effect for words (see Figure 2). Vector rescaling (McCarthy & Woods, 1985) was used to assess the topographical interaction, reveling an Item Type (objects and words) × Electrode (28) interaction [F (27, 405) = 2.160, p <0.001] Greenhouse-Geisser uncorrected. With a Greenhoue-Geisser correction, however, the interaction is not significant (p = 0.111). Further, it should be noted that the test of sphericity could not be performed since there are more levels of the factor of electrodes than there are participants.

700-800 ms epoch

The ANOVA showed an Item Type main effect [F (2, 30) = 24.651, p <0.001], indicating differences between item types, and an Item Status main effect [F (1, 15) = 6.197, p <0.025], reflecting old/new effects in general. Furthermore, a three-way Item Type × Location × Hemisphere interaction [F (6, 90) = 3.862, p <0.002] was evident, indicating differences in topography across stimuli type, and an Item Status × Location × Hemisphere interaction [F (12, 180) = 3.440, p <0.007], indicating differences in old/new effects over scalp sites. The follow up ANOVA gave no significant results for faces. As Figure 2 suggests, there seems to be an old/new difference, albeit smaller, for faces at anterior electrode sites. An ANOVA was thus conducted using an alternative set of electrodes F3, FZ, F4, FC1, FCZ, FC2, C1, CZ, C2). The analysis showed an Item Status main effect [F (1, 15) = 4.920, p <0.042], demonstrating the old/new effect for faces at these frontal electrode sites, and an Item Status × Location × Hemisphere interaction effect [F (4, 60) = 2.781, p <0.035], which was due to the mid-frontal distribution of the effect.

For objects, a main effect for Item Status [F (1, 15) = 5.721, p <0.030] and an interaction effect for Item Status × Location × Hemisphere [F (12, 180) = 4.302, p <0.003] was evident in the late time window, reflecting the topographical shift from anterior to posterior electrode sites. There were no effect for words (Maximal F > 2, NS).

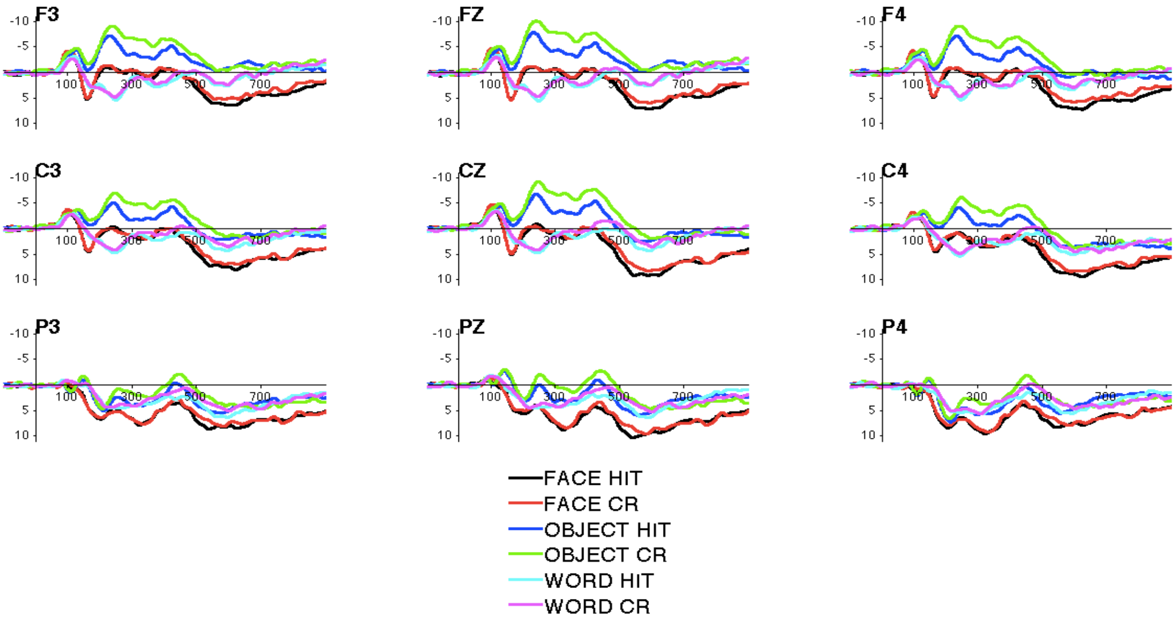

Figure 1. *Group-average ERP waveforms for items correctly encountered as old (Hits) and correctly encountered as new (Correct rejections) for all stimuli categories (Amplitude measured in µV).*

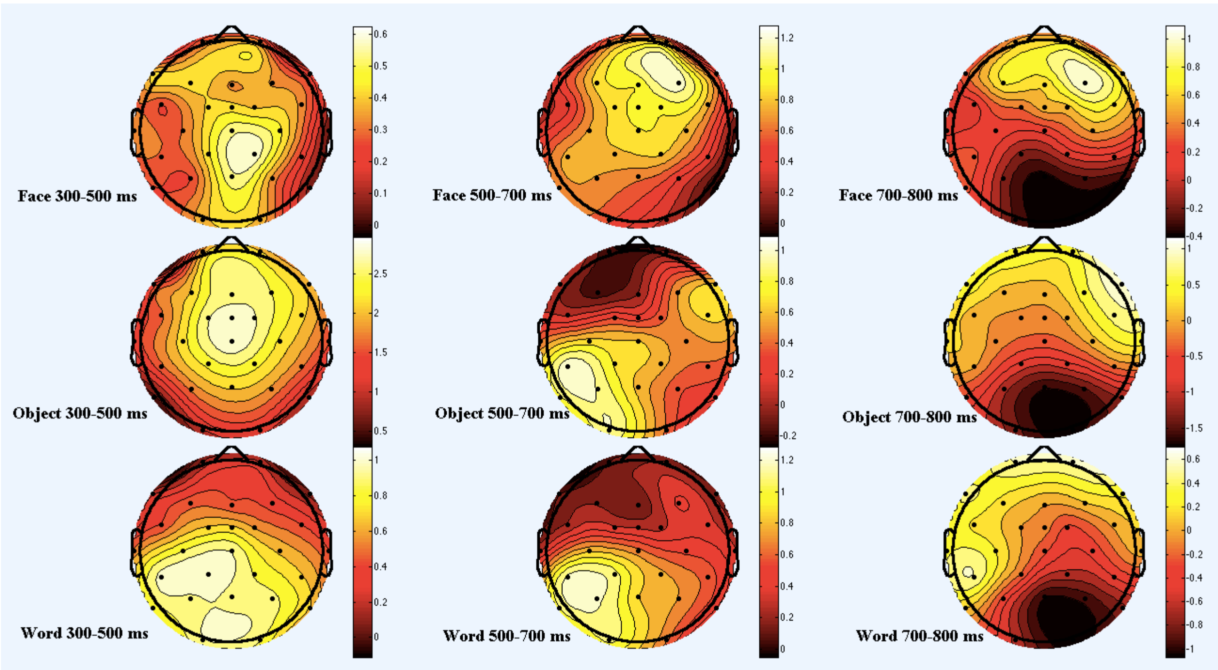

Figure 2. *Scalp topography of the ERP old/new effects (mean amplitudes differences between Hits and Correct rejections). The 300-500 ms time frame is shown to the left, the 500-700 ms window in the middle and the late 700-800 ms window to the right. The top pictures show effects associated with faces, the middle row effects for objects and bottom figures demonstrate the effects of words. The color scale represents ERP amplitude values, where a high positive value (measured in µV) corresponds to a lighter color and darker to negative values.*

Discussion

The aim of the study was to further examine the content-specific nature of the neural correlates of recognition memory by comparing ERPs elicited by items correctly endorsed as old and items correctly rejected as new for faces, objects and words.

As expected, there were evident memory effects that differed temporally as a function of material, where an old/new effect was evident in the early epoch (300-500 ms) for objects, but not for faces. The present study demonstrated a large anterior effect for objects in the early time window, persisting through the 500-700 ms epoch where it shifted to a more posterior scalp distribution which continued throughout the 700-800 ms epoch, whereas faces elicited a smaller anterior old/new effect only in the later time window (700-800 ms). The study replicated the previously found anterior old/new effect for objects, but not the previously found effect for faces (Duarte et al., 2004; Galli & Otten, 2011; Johansson, Stenberg & Lindgren, 2002; Kuo & Van Petten, 2006; MacKenzie & Donaldson, 2009; Ranganath & Paller, 2000; Yick & Wilding, 2008). Words showed a widespread old/new effect 500-700 ms post-stimuli onset.

According to the reinstatement hypothesis, the neural correlates of recollection are dependent on material-specific processes, confirmed by differences in neural activity across type of stimuli. In contrast to previous research, faces were temporally dissociated from objects, which contradicts the suggestion that material-dependent effects operate principally on differences between verbal and visual information. Instead we suggest that the unexpected differences between objects and faces are due to distinctions between nameable versus non-nameable material, rather than differences in visual and verbal properties per se.

As objects share the characteristics of visual features with faces, they also share the verbal features characteristic for words, which allows for both a perceptual and a conceptual encoding of the material. Just as a presentation of a word activates an entire conceptual network of associations to the reader, a nameable object share the same semantic content, evoking conceptual intern associations across the semantic network. These different features associated with the different item types would affect the encoding and storing of the material different and therefore also the retrieval of the episode (Tulving & Thomson, 1973), such that unknown faces are stored as perceptual representations and objects are stored as associations between perceptual and semantic representations associated with the object. These differences in attributes across the different stimulus types provide an explanation of the distinct ERP old/new effects for faces and objects such that objects evoke a richer experience compared to faces and words, hence the earlier anterior effect for objects. As the behavioral data demonstrates, there were differences in accuracy such that memory performance was better for both objects and words compared to faces. This reflects the fact that participants experienced more difficulties when trying to remember faces, supporting a distinction between nameable and non-nameable information as responsible for the distinct ERP effects.

Furthermore, the behavioral data also showed that there was no difference in confidence between stimuli type, indicating that memory for faces were poorer and yet followed by just as high confidence in judgments as for the other stimuli categories. Given that high confidence reflects recollection-based responding (Dunn, 2004), the results indicate that recognition of faces was indeed followed by recollection to the same degree as any other item, and it may be that the later and more anterior old/new effect evident here for faces is in fact a detained early anterior old/new effect. As discussed above, an unknown face has no conceptual meaning or semantic label associated to it, whereas the participant must rely only on its perceptual features when scanning the face for encoding, resulting in a shallower encoding. Moreover, during test, visual features will be the only cues to relay on and due to the random variation of stimuli type, the search for and recovery of episodic content will be delayed. As suggested by previous research, different cognitive operations may be at work when different stimuli is either randomly displayed or blocked according to category (Galli & Otten, 2011; Wilding & Nobre, 2001). To alternate the processing of retrieval cues, participants must flexibly adopt different retrieval orientations, i.e. cognitive states, to adapt processing of targets to the demands of the specific mnemonic task (Rugg & Wilding, 2000). When stimuli of different types are blocked, participants may adopt the same cognitive operations, or retrieval orientation, throughout the trials, whereas in an intermixed setting a specific type of stimuli is processed through specific cognitive operations that cannot be maintained over trials. Instead subjects are demanded to re-set processes according to what stimuli type that occur trial after trial (Wilding & Nobre, 2001).

In line with the notion that task switching can affect memory performance, it is reasonable to believe that unknown faces are more affected by task switching costs due to their low inter-item discrimination and poorer episodic content, obstructing the search for a match in memory and delaying the recovery of the episode. A perceptual memory trace, without a verbal or semantic label, may take a longer time to retrieve in a varied task. The distinction between nameable and non-nameable material as an explanation for a delayed anterior old/new effect for faces is consistent with previous research where encoding of material have been guided by associative encoding tasks (Johnson et al., 2008; Galli & Otten

2011; MacKenzie & Donaldson, 2009). For instance, MacKenzie and Donaldson (2009) demonstrated an anterior old/new effect (500-700 ms) for faces encoded together with a name, whereas Galli and Otten (2011) demonstrated an anterior effect for both faces and objects (300-500 ms) after an associative encoding task including an auditorily presented location. In both studies, participants were presented with faces paired with conceptually meaningful labels, facilitating both encoding and retrieval of the episodic content, hence the earlier anterior effects.

Moreover, we would like to point out that the anterior material-specific old/new effects found here, not necessarily reflects the reinstatement of cortical encoding-related neural activity. Instead it might be possible that the anterior ERP effects for the different stimuli categories, represents prefrontal cortical (PFC) mechanisms involved in recollection memory.

Prefrontal cortex is considered to house a control network of processes related to contextual recollection supporting (a) specification of retrieval orientation, (b) evaluation and elaboration of test probes according to retrieval orientation and (c) evaluation and selection of retrieved episodic content corresponding to task demands, functioning like a working memory supporting recollection (Anderson et al., 2011; Dobbins & Wagner, 2005; Dobbins & Sanghoon, 2006; Simons, Owen, Fletcher & Burgess 2005; see Simon & Spiers 2003, for review).

As argued above, the later anterior old/new effect for faces might be a delayed early effect due to differences in nameable versus non-nameable information in combination with the task-switching nature of the test, making it harder to search for a match in memory and recover the episode. Since PFC arguably is involved in the operations underlying this search and match process, the present data might suggest that the anterior effect observed for faces manifests the delayed monitoring and evaluative operations of the PFC.

In line with this notion, switching fast between stimuli would influence PFC's monitoring of retrieval plans negatively by delaying the process. As indicated by the behavioral data, the task-switching setting affected accuracy in the face condition to a greater extent, possibly reflecting a delayed evaluation and matching process supported by the PFC. Such an effect was not evident in terms of reaction time, showing no differences across item types, which limits the interpretation accordingly.

Furthermore, holding relevant representations online, while evaluating them according to task-oriented demands, would be affected by varying levels of access to the representations stored in memory. A richer material with a greater overlap between test condition and memory trace would be easier for PFC to maintain active, hence greater accuracy and an earlier anterior old/new effect for objects. A difficult task on the other hand would make it difficult to keep many competing representations online and delay the processes of monitoring and evaluation, hence the later anterior old/new effect for faces.

PFC is also involved in the evaluation of the features of test probes, focusing attention towards the attributes of interest for the mnemonic task (Dobbins & Wagner 2005; Dobbins & Sanghoon, 2006; Simons et al., 2005). Interestingly, fMRI studies have demonstrated dissociations in parts of the PFC associated with such operations, such that specific regions supports evaluation of visuo-perceptual versus conceptual attributes of the test item respectively (Dobbins & Wagner, 2005; Dobbins & Sanghhon, 2006), corresponding to dissociations between ERP old/new effects for perceptual and conceptual information.

Apparently, different tasks make different demands where different types of information may serve as cues for recollection. A certain overlap is necessary between study and test, so that the task overlaps with the encoded memory trace sufficient enough for a match between test probe and memory, to generate a confident old response. In the present study, the overlap may have been greater for objects due to their comprehensive content of both visual and verbal information generating a wide representation in memory easier to access. If one assumes that specific materials or item types leads to specific encoding-situations which in turn leads to differences in retrieval according to retrieval cues, it is possible that in the present study the richer associative characteristic of objects provides a greater overlap between study and test (Rugg & Wilding, 2000). Unknown faces that contains less information, and perhaps more abstract information, would possess a poorer overlap, hence the temporal differences in matching and recollection. Further assumed that the verbal information attached to faces in previous studies affects the memory trace to be recollected, the overlap between study and test may have been greater and therefore contributed to a faster search and match in comparison with the present study. As expressed by the encoding specificity principle (Tulving & Thomson, 1973), “specific encoding operations performed on what is perceived determines what is stored, and what is stored determines what retrieval cues are effective in providing access to what is stored” (p.369), objects, faces and, words evoke different encoding operations resulting in differences in how the material is stored in and retrieved from memory.

Finally, MacKenzie and Donaldsson (2009) argued that the material-specific ERP effects might not reflect the reinstatement of content but rather the cortical reinstatement of context. In accordance to the present results with respect to previous studies, one could argue that the material-specific effects observed rely on operations based on both context and content. The differing results across studies might simply reflect distinctions between how different encoding tasks across different stimuli categories results in different encoding situations, which leads to different strategies for retrieval. As stated above, different tasks make different demands where distinct information is used as retrieval cue, and with that in mind it could be that material-specific correlates of recollection are based upon content or context or both, depending on if it is contextual or content-related features that guides encoding and later serves as retrieval cues. The overlap between objects and faces found in Galli and Ottens (2011) study, in comparison with the results in the present one, would then be explained according to encoding situation. The similar effect found for faces and objects in the former study might be due to an encoding situation where participants adopted a more context-related retrieval orientation for both faces and objects in combination with visual information (hence the overlap in ERP's between stimuli categories), whereas in the present study participants relayed only on content-related features such as visual aspects and semantic information (hence the distinction between ERP's for faces and objects). Therefore the inconclusive results across studies, suggests that material-specific ERPs depend on both contextual and content-related information, depending on encoding and retrieval situation.

The speculative nature of the argumentation above inquires further research in the matter and as we were unaware that memory performance and memory effects may vary according to task-related demands and as a consequence of how different material affect encoding, it would be of great interest to investigate how different materials cause specific encoding situations. A subsequent study may use a stay-switch design to isolate processes affected by degree of difficulty in adopting the retrieval orientations demanded for the tasks (Wilding & Nobre, 2001). In such a stay-switch design, different stimulus types with different levels of perceptual and conceptual features presented in blocked or intermixed conditions varying throughout the experiment, would force the participant to monitor different retrieval plans according to what information to rely on in the search and matching of test item and corresponding memory trace. According to the present results, an earlier anterior old/new effect should be expected for the blocked conditions regardless of material, since task-switching costs will be reduced and there will be no delay in the searching and matching processes. Furthermore, future research is needed to compare differences across encoding tasks to assess how different forms of encoding of stimulus type will affect task-orientation and the use of distinctive cues during retrieval.

At last, there may be weaknesses in the present study to discuss further. The relatively small number of sixteen participants was sufficient to minimize item-specific effects and counterbalance the conditions of item sets and ensure an equal distribution across experiment blocks. However, a larger number of participants would allow a stronger statistical power for the results presented, and possibly there may have been a stronger interaction with location for words in the 500-700 ms epoch. As it was impossible to test for sphericity, due to more electrodes than participants, it remains unclear if a Greenhouse-Geisser correction is needed. Doubling the number of participants would allow for such a sphericity test and the significant, or non-significant, interaction reflecting the more posterior distribution of the widespread old/new effect for words could be confirmed.

Another potential weakness in the experimental design was the lack of an alternative confidence response for incorrect old/new responses, which refrained participants from making accurate ratings of erroneous old/new responses. Instead, participants were likely to respond *Uncertain* if they were aware of their erroneous old/new response, which could have affected the data collected.

Also, the word stimuli material was collected from a relatively new Swedish database (Språkbanken) with limited material sources. The database uses written frequencies based upon Swedish magazines, making it uncertain how representative the frequency values are fore the actual used Swedish language. This may have caused biases in the frequency analysis performed to collect a word stimuli material comparable with English standards where more extensive research on language norms and word frequencies and association norms exists (Kucera & Francis, 1967).

In conclusion, the present data supports the material-specific independence of the neural correlates of recollection and further extends previous findings by demonstrating differences between recollected objects and faces. As previously stated, content-specific ERP effects seem to be essential for successful memory retrieval and the effects seem to reflect different processing of different information. In contrast to previous studies, we suggest that the distinct ERPs for the different item types reflect differences in encoding and retrieval of different representations due to task-demands and distinctions between nameable and non-nameable material, where perceptual and conceptual attributes of the items are critical to how encoding and retrieval differs across item type. Further research is needed to assess how different as well as overlapping attributes across item types will affect the spatio-temporal properties of ERPs related to different item types, especially the anterior old/new effect evident for faces and objects.

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Appendix

List of objects and words

Frequency measured in counts per million words

Object Names	Set	Words	Frequency	Length	Set
ägg	1	affär	19.1	5	1
anka	1	band	48.2	4	1
äpple	1	smör	25.2	4	1
badmintonboll	1	bank	14.3	4	1
balong	1	dans	24.6	4	1
barbiesko	1	elev	13.0	4	1
båt	1	flaska	14.1	6	1
bil	1	gäst	8.6	4	1
blommor	1	hjälte	8.5	6	1
bokstöd	1	hosta	6.2	5	1
borste	1	hotell	29.6	6	1
chili	1	kanel	4.6	5	1
dartpil	1	kjol	7.9	4	1
disksvamp	1	kanon	9.6	5	1
donut	1	kavaj	6.2	5	1
fisk	1	kofta	5.7	5	1
fotbollspelare	1	kompis	45.2	6	1
garn	1	lampa	5.3	5	1
genilåda	1	lögn	6.5	4	1
glödlampa	1	lust	25.9	4	1
gris	1	medlem	39.3	6	1
gubbe	1	moster	7.5	6	1
gurka	1	mynt	6.1	4	1
hammare	1	orsak	21.6	5	1
hårspänne	1	opera	6.9	5	1
hatt	1	paket	33.3	5	1
jonglerboll	1	päron	4.3	5	1
kaktus	1	paus	22.9	4	1
kapsyl	1	piano	8.9	5	1
klocka	1	planet	25.4	6	1
kontakt	1	rygg	21.0	4	1
kork	1	sand	6.6	4	1
kronärtskocka	1	silver	16.4	6	1
kub	1	sång	22.8	4	1
leksak	1	storm	8.7	5	1
limstift	1	test	16.8	4	1
lypsyl	1	yoga	4.2	4	1
mått	1	karta	7.4	5	1
mugg	1	vinter	23.7	6	1

nalle	1	virus	8.3	5	1
näsdukar	1	arena	10.9	5	1
nycklar	1	ängel	5.2	5	1
parfym	1	soldat	5.9	6	1
penna	1	dagis	28.3	5	1
plåtburk	1	drink	7.5	5	1
prydnad	1	fartyg	21.1	6	1
rep	1	fiende	6.6	6	1
schackpjäs	1	gitarr	12.2	6	1
skål	1	glas	38.4	4	1
smurf	1	godis	30.5	5	1
snögubbe	1	gåta	4.0	4	1
strumpor	1	magi	4.3	4	1
tändare	1	krona	13.9	5	1
tejp	1	hals	7.8	4	1
tennisboll	1	hjärna	12.8	6	1
timglas	1	hjärta	40.9	6	1
tomat	1	idiot	9.9	5	1
trähund	1	idol	9.3	4	1
trumma	1	jakt	21.1	4	1
väderkvarn	1	juice	4.8	5	1
äggkartong	2	kapten	9.2	6	2
annanas	2	kors	8.1	4	2
askfat	2	luft	17.8	4	2
badring	2	lista	38.9	5	2
bananer	2	matta	5.6	5	2
baseball	2	mord	32.2	4	2
batteriladdare	2	morot	4.7	5	2
blomkål	2	natur	19.2	5	2
bok	2	plast	7.8	5	2
bomullsrondeller	2	rosa	36.1	4	2
bröd	2	sallad	16.3	6	2
citron	2	skåp	5.3	4	2
deodorant	2	säng	38.4	4	2
dockfamilj	2	syskon	14.0	6	2
fällkniv	2	tiger	4.6	5	2
flaska	2	vardag	20.3	6	2
frigolit	2	väsen	6.4	5	2
gem	2	vinst	44.5	5	2
geting	2	villa	11.0	5	2
gran	2	tvätt	11.3	5	2
groda	2	album	33.7	5	2
gul grej	2	artist	12.5	6	2
häftapparat	2	avfall	7.6	6	2
handduk	2	bänk	5.1	4	2
häst	2	vittne	7.2	6	2

jojo	2	larm	12.7	4	2
julgranskula	2	disk	5.0	4	2
kamera	2	expert	11.2	6	2
klädnypa	2	fordon	19.3	6	2
knivställ	2	frisör	5.6	6	2
korg	2	golf	9.1	4	2
kotte	2	golv	8.7	4	2
kruka	2	träd	24.5	4	2
lastbil	2	idrott	10.7	6	2
lime	2	jurist	7.8	6	2
ljus	2	klubb	22.5	5	2
majs	2	kniv	10.3	4	2
mobiltelefon	2	kostym	7.1	6	2
nagellack	2	kyrka	36.8	5	2
napp	2	lapp	5.9	4	2
nöt	2	länk	23.5	4	2
paprika	2	last	21.0	4	2
partytuta	2	lokal	28.7	5	2
pepparkvarn	2	manus	10.8	5	2
potatis	2	mark	53.0	4	2
rädisor	2	märke	16.7	5	2
sax	2	moln	10.1	4	2
sjöjungfru	2	natur	19.2	5	2
sko	2	olycka	14.1	6	2
snäcka	2	olja	28.9	4	2
sten	2	regn	29.2	4	2
strykjärn	2	order	21.1	5	2
tärning	2	tält	7.6	4	2
tekanna	2	torg	18.2	4	2
tequilahatt	2	tempel	4.2	6	2
toarulle	2	trafik	21	6	2
trådrulle	2	trappa	7.3	6	2
troll	2	växt	14.2	4	2
väckarklocka	2	vision	9.9	6	2
värmeljus	2	vinkel	4.7	6	2
vas	filler	jord	16.4	4	filler
vattenkanna	filler	böter	14.6	5	filler
vikt	filler	fågel	12.2	5	filler
visselpipa	filler	krona	13.9	5	filler
vitlök	filler	cykel	16.9	5	filler