BRAIN RESEARCH 1283 (2009) 102–114

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Research Report

Semantic and perceptual effects on recognition memory: Evidence from ERP

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ARTICLE INFO

Article history:
Accepted 23 May 2009
Available online 6 June 2009

Keywords:
Recognition memory
ERP
Levels of processing
Perceptual match
Font fan

ABSTRACT

The present experiments examined how semantic vs. perceptual encoding and perceptual match affect the processes involved in recognition memory. Experiment 1 examined the effects of encoding task and perceptual match between study and test fonts on recognition discrimination for words. Font fan was used to determine the effect of distinctiveness on perceptual match. The semantic encoding task and perceptual match for distinctive items led to better recognition memory. Event-related brain potentials (ERPs) recorded from the human scalp during recognition memory experiments have revealed differences between old (studied) and new (not studied) items that are thought to reflect the activity of memory-related brain processes. In Experiment 2, the semantic encoding task and perceptual match for distinctive words led to better recognition memory by acting on both familiarity and recollection processes, as purportedly indexed by the FN400 and parietal old/new effects. Combined these results suggest that the semantic encoding task and perceptual match for distinctive items aid recognition memory by acting on both familiarity and recollection processes.

It is well known that memory can benefit from semantic over perceptual encoding ("levels of processing" (LOP)); (Craik and Lockhart, 1972; Craik and Tulving, 1975). In addition to the benefits of semantic encoding, recognition memory can be facilitated when there is a perceptual match between study and test (Ecker et al., 2007a, 2007b; Gardiner et al., 2006; Goldinger et al., 2003; Graf and Ryan, 1990; Groh-Bordin et al., 2006; Hirshman et al., 1999; Hunt and Elliot, 1980; Nairne, 2002; Reder et al., 2002). Although the perceptual match between study and test may not always lead to better memory (Hunt and Elliot, 1980; Nairne, 2002), there is evidence suggesting that under the right conditions perceptual match aids recognition memory.

Two competing theories have tried to explain the conditions under which perceptual match contributes to recognition memory. Graf and Ryan (1990) suggest that perceptual match effects on recognition memory are not automatic but depend on orienting subjects to pay attention to perceptual features. Graf and Ryan (1990) had subjects study words presented in Pudgy or Shadow fonts, and they rated the readability or pleasantness of the words. The readability task forced subjects to focus on the perceptual features of the words whereas the pleasantness task forced subjects to focus on semantic information. Recognition was later tested with studied words appearing in the same or a different font. Graf and Ryan (1990) found that recognition was better for words studied and tested in the same font following the readability task but not following the pleasantness task. These results suggest that the effect of perceptual match on recognition memory is not automatic but depends on orienting subjects to pay attention to perceptual features.

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doi:10.1016/j.brainres.2009.05.091

Others argue that perceptual match affects recognition memory when items are distinctive (Hunt and Elliot, 1980; Reder et al., 2002). One example of the effect of distinctiveness is the "fan effect" which refers to the finding that subjects are slower and less accurate to recognize words when there were more words sharing a font than when the font was unique to the word (Reder et al., 2002). Reder et al.'s (2002) Experiment 2 demonstrated a perceptual fan effect by having subjects study words that were presented in a unique font (low font fan) and words that were presented in a font shared by 11 other words (high font fan). One group of subjects studied the words and rated the legibility of each word. Another group studied the words and rated the pleasantness of each word. During the recognition test half of the studied words were presented in the same font as study (match), one quarter were presented in another font seen at study (non-match), and one quarter were presented in a new font not previously seen (novel). Recognition was more accurate for matched than non-matched font words and this effect interacted with the fan effect such that the difference between matched and non-matched font fan words was greater for low than high font fan words, but these effects did not interact with the encoding task. These results indicate that distinctiveness is important for perceptual matching to aid recognition memory.

A review of the recognition memory literature suggests that recognition memory is supported by two separate processes (reviewed in Yonelinas, 2002). Whereas familiarity is more general and allows only for recognition of an item without recall of specific information, recollection allows for direct recall of information about items or episodes. Event-related potentials (ERPs) have been used to study the neural correlates of recognition memory. The FN400 component is characterized as being more positive for correctly classified old than new items between approximately 300 and 500 ms post-stimulus and reaches peak amplitude approximately 400 ms post-stimulus over frontal regions. The parietal old/new effect is more positive for correctly classified old than new items between approximately 500 and 800 ms post-stimulus and reaches peak amplitude approximately 600 ms post-stimulus over parietal regions (Curran, 1999, 2000; Curran and Cleary, 2003; Curran and Dien, 2003; Curran and Friedman, 2004; Curran et al., 2002; Friedman, 2005; Friedman and Johnson, 2000; Mecklinger, 2000; Paller et al., 2007; Rugg et al., 2000; Rugg and Curran, 2007; Rugg et al., 1998; Schloerscheidt and Rugg, 2004; Wilding and Rugg, 1996).

The FN400 is thought to index familiarity as it is able to separate old from new items, but does not vary with the recollection of specific information from the study episode. The FN400 is similar for studied words correctly judged as old or reversed plurality words (e.g. studied DOG, tested DOGS) incorrectly judged as old (Curran, 2000) and for studied pictures correctly judged as old and opposite orientation pictures incorrectly judged as old (Curran and Cleary, 2003). The parietal old/new effect is thought to index recollection because it not only separates old from new items, but does vary with the recollection of specific information from the study episode. The parietal old/new effect is greater for studied words correctly judged as old compared to reversed plurality words incorrectly judged as old (Curran, 2000) and for studied pictures correctly judged as old compared to opposite orientation pictures incorrectly judged as old (Curran and Cleary, 2003). The parietal old/new effect is also greater with successful compared to unsuccessful source judgments (Senkfor and Van Petten, 1998; Wilding and Rugg, 1996). These results provide converging evidence using different task manipulations that the FN400 indexes familiarity whereas the parietal old/new effect indexes recollection (for further review see Curran et al., 2006b; Rugg and Curran, 2007).

Although it has been shown that recognition memory can be facilitated by semantic encoding and by a perceptual match between study and test, it is not yet resolved how these factors affect the underlying processes. A number of studies have attempted to address these questions using several different approaches, but the results have been somewhat variable. Some studies have shown that LOP affects both familiarity and recollection processes. For example, using the process dissociation procedure, the remember/know procedure, and tracing receiver operating characteristic (ROC) curves, Yonelinas (2001) found that semantic compared to perceptual encoding led to increases in familiarity and recollection. Manipulating LOP across blocks Rugg et al. (2000) found ERP differences between old and new words diverging between shallow and deep encoding conditions between 300–500 ms and 500–800 ms. But other studies only found LOP to affect later recollection processes, as indexed by the parietal old/new effect, when shallow vs. deep encoding tasks were mixed within blocks (Paller and Kutas, 1992; Rugg et al., 1998).

Some studies have suggested that perceptual matching only affects recollection processes (Hirshman et al., 1999; Reder et al., 2002). For example, Hirshman et al. (1999) studied the effects of perceptual match on familiarity and recollection in two sessions, one in which subjects were injected with a saline solution and another in which they were injected with midazolam, which primarily hurts recollection (Curran et al., 2006a; Hirshman et al., 2001). In each session the subjects studied words and non-words visually or aurally and were later asked to recognize words that were presented visually. The subjects were significantly better at recognizing words that were studied and tested in the same modality than they were at recognizing words that were studied and tested in a different modality in the saline but not the midazolam condition. These results suggest that perceptual match affects recognition memory by acting only on recollection processes. Reder et al.'s (2002) Experiment 3 manipulating font fan along with perceptual matching required subjects to make remember and know judgments at test. Because their model made specific predictions regarding how font fan would affect perceptual match for recollection, they focused on "remember" responses. The results showed that for hits subjects made more remember responses for matched than non-matched font words. This effect was bigger for low than high font fan words. Although familiarity was not discussed, we were able to estimate familiarity from "know" and "remember" responses from their Table 3. Using Yonelinas' procedure to estimate familiarity (Familiarity = K/1 − R) (Yonelinas and Jacoby, 1995), it appears that familiarity was numerically greater for matched than non-matched font words for low but not high font fan words. Thus, familiarity might have also been affected by perceptual matching in Reder et al.'s (2002) Experiment 3.

ERP studies have suggested that familiarity can also be affected by perceptual matching (Ally and Budson, 2007; Curran and Doyle, submitted; Ecker et al., 2007a, 2007b; Groh-Bordin et al., 2006; Schloerscheidt and Rugg, 2004). Three studies had subjects study mixed lists of pictures and words followed by test items with matched or non-matched format (e.g. study picture/test picture, study picture/test word) (Ally and Budson, 2007; Curran and Doyle, submitted; Schloerscheidt and Rugg, 2004). These studies found that the FN400 was more positive for matched than non-matched formats from study to test, regardless of whether matched items were pictures or words whereas the parietal old/new effect was more positive for studied pictures regardless of format matching. These studies suggest that the FN400 is sensitive to perceptual match whereas the parietal old/new effect is sensitive to study format. In addition, a set of recent studies recorded ERPs while subjects were tested on pictures that were identical to studied items or were presented in a different color from study to test (Ecker et al., 2007a, 2007b; Groh-Bordin et al., 2006). Ecker et al. (2007b) showed that the familiarity-related FN400 was greater for perceptually matched than non-matched pictures but did not find any differences between matched, non-matched, and new pictures for the parietal old/new effect, presumably because subjects were relying on factors other than recollection to make recognition decisions. Ecker et al. (2007a) and Groh-Bordin et al. (2006) found that for both the FN400 and parietal old/new effect, there were greater differences between old and new pictures that perceptually matched between study and test than were non-matched.

Therefore, previous research has shown conflicting results relating LOP and perceptual match effects to familiarity and recollection processes. Regarding LOP effects, behavioral experiments showed that both familiarity and recollection were affected by LOP (Yonelinas, 2001). A past ERP study separating encoding tasks into separate blocks found that the FN400 familiarity and the parietal recollection effects were affected by LOP (Rugg et al., 2000), whereas other ERP studies suggested that only the parietal recollection effect is affected by LOP when different encoding tasks are mixed within the same lists (Paller and Kutas, 1992; Rugg et al., 1998). It is possible that blocking encoding conditions enhances LOP effects whereas mixing shallow and deep encoding conditions weakens LOP effects. Therefore, we predicted that, like separating encoding tasks into separate blocks, having subjects do different encoding tasks on separate days would elicit LOP effects for both familiarity and recollection, as indexed by the FN400 and parietal old/new effects.

Regarding perceptual match effects, past ERP studies manipulating picture color found that both the FN400 and parietal old/new effects were sensitive to perceptual match (Ecker et al., 2007a; Groh-Bordin et al., 2006), whereas studies manipulating word/picture format found that the FN400 was sensitive to perceptual match (Ally and Budson, 2007; Curran and Doyle, submitted; Schloerscheidt and Rugg, 2004). It is possible that using pictures masks the effects of perceptual match. Because pictures are much more memorable than words (picture superiority effect; e.g., Mintzer and Snodgrass, 1999), studying pictures could overpower any influence that perceptual matching might have on the parietal recollection effect. Past behavioral studies suggest that perceptual match affects only recollection processes (Hirshman et al., 1999). It is possible that Hirshman et al. (1999) did not find perceptual match effects for familiarity because the perceptual information was not distinctive (i.e., visual/auditory modalities have a high fan when each are associated with half the studied words). Reder et al.'s (2002) Experiment 3 found that distinctiveness enhanced perceptual match effects for "remember" responses suggesting that perceptual match affects recollection; but, as stated previously, their results suggest that familiarity was numerically greater for matched than non-matched font words for low but not high font fan words. Therefore, we manipulated the distinctiveness of fonts, and predicted that distinctive fonts would elicit perceptual match effects for both familiarity and recollection, as indexed by the FN400 and parietal old/new effects. The present experiments were based on the behavioral paradigm used by Reder et al.'s (2002) Experiment 2[1] which manipulated LOP, distinctiveness, and perceptual matching.

1. Experiment 1

The purpose of Experiment 1 was to replicate Reder et al.'s (2002) results using a slightly different design. Following Reder et al.'s (2002) Experiment 2 subjects studied words in low and high font fans. Compared to Reder et al.'s (2002) Experiment 2 between subjects LOP manipulation, here the same subjects were asked to rate the pleasantness of the word (pleasantness task) or rate the legibility of the word (legibility task) in different sessions. By doing so subjects were oriented to pay attention to semantic information in the pleasantness task and to the perceptual features of the words in the legibility task. Later subjects were tested on their memory for words that appeared in matched or non-matched fonts. Because the focus was on matched vs. non-matched fonts, no novel fonts were used at test as in Reder et al.'s (2002) Experiment 2. Rather than using simple old/new judgments as in Reder et al.'s (2002) Experiment 2, subjects were asked to rate their confidence that each word was old or new in order to use ROC analyses to accurately measure discrimination and response bias, without assuming that old and new memory strength distributions have equal variance.

1.1. Method

1.1.1. Subjects

Thirty-five students participated in the experiment for payment. All subjects gave informed consent. Data from three subjects were discarded because of failure to complete both experimental sessions. Of the 32 subjects analyzed there were 11 male and 21 female subjects ranging from 18 to 28 years old.

1.1.2. Stimuli

Stimuli consisted of 960 words and 264 fonts roughly equated for readability (e.g. **GILL SANS ULTRA** and SAND). Twenty-four additional words and 12 additional fonts were

[1] Reder et al.'s (2002) Experiment 3 that used remember/know judgments and was discussed in the Introduction did not manipulate LOP, so their Experiment 2 is most relevant to the present work.

used for practice. The words were common English words roughly equated for word frequency (M=8.84, SD=9.69, range 0:39) according to the Kucera and Francis (1967) word norms and familiarity (M=6.78, SD=.42, range 4.08:7) according to Coltheart (1981). Words were randomly presented in one of 264 possible fonts depending on condition. All words were presented in upper case in white on an LCD computer monitor on a black background subtending a visual angle of approximately 2.3°.

1.1.3. *Design*

Memory status (match, non-match, new), encoding task (pleasantness, legibility), and font fan (low, high) were manipulated within subjects. Subjects participated in two sessions, one in which they performed the pleasantness task and the other in which they performed the legibility task. Assignment of encoding task to the first or second session was counterbalanced across subjects. Word lists were counterbalanced across encoding task and font lists were counterbalanced across word lists. In each session subjects were presented with both levels of font fan and font matching in each of six blocks. Test key assignments were counterbalanced across subjects.

1.1.4. *Procedure*

Each one-hour session began with a practice study and test block. Practice blocks consisted of 20 study words and eight test words, after which each subject completed the six study-test blocks.

In each study phase subjects viewed 40 words. Half of the study words were presented in a unique font (low font fan) and half were presented in a font shared by nine other words (high font fan). In one session subjects studied the words and, using their index and middle finger of both hands, rated the pleasantness of each word according to a Likert scale (very unpleasant, unpleasant, pleasant, and very pleasant). In the other session subjects studied the words and, using their index and middle finger of both hands, rated how legible the word was according to a Likert scale (very illegible, illegible, legible, and very legible). Each word was preceded by a 600 ms fixation (+). Words were presented for 1000 ms during which subjects made their response. Subjects were allowed to rest for 2 min following each study block.

After each study phase subjects were tested on their memory for studied words. The test phase contained the 40 studied words intermixed with 40 new words. Previously studied words were divided such that half of the low font fan old words and half of the high font fan old words appeared in the same font used at study (match) and half appeared in another font used at study (non-match). Half of the new words were presented in a low-fan font and half were presented in a high-fan font. Subjects were tested on 20 words at a time with a break in between. Test trials included a variable duration (500–1000 ms) fixation (+) followed by a test word. Each test word was presented for 2000 ms followed by a question mark. Upon appearance of the test word subjects were able to respond. Using the first three fingers of both hands subjects pressed a key for surely, likely, or maybe studied depending on how confident they were of their answer or surely, likely, or maybe non-studied, depending on how confident they were of their answer.

1.2. Results

The slope of the z-score transformed ROC curve was less than 1 ($s=0.88$), indicating that variance was greater for the old than new word distribution, as is often observed (Glanzer et al., 1999; Ratcliff et al., 1992). Analyses were performed on discrimination (d_a) and response bias (c_a), which do not assume equal variance between the old and new word distributions. Because there was no font match for new words, hits were compared to a common false alarm (FA) rate. For example, the legibility/low font fan/match and legibility/low font fan/non-match conditions were both compared to the FAs for the legibility/low condition. *da* and *ca* were analyzed with a task (pleasantness, legibility) × font fan (low, high) × font match (match, non-match) repeated measures analysis of variance (ANOVA).

Table 1 shows the behavioral results from Experiment 1. Discrimination (*da*) was higher following the pleasantness (M $da=1.90$) than the legibility task (M $da=1.00$) ($F(1,31)=148.94$, $MSE=0.35$, $p<0.01$), for low (M $da=1.49$) than high font fan words (M $da=1.42$) ($F(1,31)=5.16$, $MSE=0.07$, $p=0.03$), and for matched (M $da=1.67$) than non-matched font words (M $da=1.24$) ($F(1,31)=132.54$, $MSE=0.09$, $p<0.01$). Task interacted with font fan such that the difference between low and high font fan words was greater following the legibility than the pleasantness task ($F(1,31)=7.64$, $MSE=0.08$, $p<0.01$). The difference between low and high font fan words was significant only following the legibility task ($F(1,31)=11.72$, $MSE=0.92$, $p<0.01$). Font fan interacted with font match such that the difference between matched and non-matched font words was greater for low than high font fan words ($F(1,31)=14.20$,

Table 1 – Behavioral data from Experiment 1.

	Condition	Ple LF	Ple HF	Leg LF	Leg HF
Hit	Match	0.89 (0.01)	0.90 (0.02)	0.77 (0.02)	0.76 (0.02)
	Non-match	0.80 (0.02)	0.83 (0.02)	0.61 (0.02)	0.66 (0.02)
FA	Match Non-match	0.17 (0.02)	0.19 (0.02)	0.27 (0.02)	0.36 (0.03)
da	Match	2.15 (0.11)	2.10 (0.10)	1.35 (0.08)	1.08 (0.07)
	Non-match	1.64 (0.09)	1.73 (0.10)	0.83 (0.06)	0.76 (0.06)
ca	Match	−0.16 (0.07)	−0.25 (0.07)	−0.06 (0.07)	−0.13 (0.08)
	Non-match	0.02 (0.07)	−0.10 (0.07)	0.18 (0.08)	0.009 (0.08)

Note. Means with standard errors in parentheses. Ple=pleasantness, Leg=legibility, LF=low font fan, HF=high font fan.

Table 2 – Reaction time data from Experiment 1.

	Condition	Ple LF	Ple HF	Leg LF	Leg HF
RT	Match	1056 (43)	1056 (41)	1191 (57)	1118 (51)
	Non-match	1118 (46)	1113 (50)	1273 (69)	1203 (58)
	New	1279 (67)	1298 (67)	1280 (61)	1271 (62)

Note. Means with standard errors in parentheses. Ple=pleasantness, Leg=legibility, LF=low font fan, HF=high font fan.

$MSE=0.03$, $p<0.01$). The difference between matched and non-matched font words was significant for both low ($F(1,31)=275.51$, $MSE=8.46$, $p<0.01$) and high font fan words ($F(1,31)=127.02$, $MSE=3.90$, $p<0.01$).

Response bias (*ca*) was more conservative following the legibility ($M\ ca=0.001$) than the pleasantness task ($M\ ca=-0.12$) ($F(1,31)=14.99$, $MSE=0.33$, $p<0.01$), for low ($M\ ca=0.005$) than high font fan words ($M\ ca=-0.12$) ($F(1,31)=16.69$, $MSE=0.25$, $p<0.01$), and for non-matched ($M\ ca=0.03$) than matched font words ($M\ ca=-0.15$) ($F(1,31)=135.76$, $MSE=0.07$, $p<0.01$). Font fan interacted with font match such that the difference between matched and non-matched font words was greater for low than high font fan words ($F(1,31)=9.59$, $MSE=0.04$, $p<0.01$). The difference between matched and non-matched font words was significant for both low ($F(1,31)=181.23$, $MSE=7.12$, $p<0.01$) and high font fan words ($F(1,31)=82.49$, $MSE=3.24$, $p<0.01$).

Reaction Times (RTs) on only correct trials were analyzed with a memory status (match, non-match, new)×task (pleasantness, legibility)×font fan (low, high) repeated measures ANOVA (see Table 2). Memory status interacted with task such that the difference between the pleasantness and the legibility task was greater for old than new words ($F(2,62)=13.43$, $MSE=12481$, $p<0.01$). Memory status interacted with font fan such that the difference between low and high font fan words was greater for old than new words ($F(2,62)=4.09$, $MSE=4479$, $p=0.02$). When RTs for new words were analyzed alone with a task×font fan repeated measures ANOVA, there were no significant condition effects. When old words were analyzed alone with a task×font fan×font match repeated measures ANOVA, RTs were faster following the pleasantness ($M\ RT=1086$) than the legibility task ($M\ RT=1196$) ($F(1,31)=5.73$, $MSE=136630$, $p=0.02$), for high ($M\ RT=1123$) than low font fan words ($M\ RT=1159$) ($F(1,31)=13.94$, $MSE=6142$, $p<0.01$), and for matched ($M\ RT=1105$) than non-matched font words ($M\ RT=1177$) ($F(1,31)=43.72$, $MSE=7483$, $p<0.01$). Task interacted with font fan such that the difference between low and high font fan words was greater following the legibility than the pleasantness task ($F(1,31)=10.87$, $MSE=6998$, $p<0.01$). The difference between low and high font fan words was significant only following the legibility task ($F(1,31)=23.08$, $MSE=161516$, $p<0.01$).

1.3. *Discussion*

The results of Experiment 1 mostly replicated those of Reder et al.'s (2002) Experiment 2. Like in Reder et al.'s (2002) Experiment 2, subjects' discrimination was better following the pleasantness task than the legibility task and for words that perceptually matched from study to test, but the perceptual match effect was only significant in the low font fan condition. Although Reder et al.'s (2002) Experiment 2 did not find a main effect of font fan or an interaction between font fan and task, their results suggest a trend such that the difference between low and high font fan words was greater following the legibility task. In the present experiment discrimination differed between low and high font fan words, but only following the legibility task. Subjects were able to form associations between words and fonts. It is likely that these associations were stronger in the low font fan condition where fonts were unique to words than in the high font fan condition when many words shared a font. It is also likely that subjects form word–font association more when they attend to the font in the legibility task. The subjects could then use these word–font associations to aid recognition when their memory was poor following the legibility task.

RT results were generally consistent with accuracy in that conditions with higher accuracy had faster reaction times (for old conditions, new conditions did not show RT differences), except for the font fan effect which was more accurate yet slower for low than high font fan words. It is possible that low font fans engage a more deliberate retrieval strategy such that font is used as a cue to remember the word studied in that font. This would make retrieval slower, but more accurate.

2. Experiment 2

The results of Experiment 1 suggest that orienting subjects to encode semantic information and perceptual match for distinctive words lead to better recognition. Studying the neural correlates of recognition memory may help determine how LOP and perceptual match contribute to the processes of recognition memory. Experiment 2 was designed to examine how LOP and perceptual match affect the purported ERP correlates of familiarity and recollection. We sought to resolve past inconsistencies regarding LOP and perceptual match effects on familiarity and recollection processes by having subjects do different encoding tasks on separate days and by manipulating the distinctiveness of fonts. As detailed earlier, it was predicted that LOP and perceptual match for distinctive words would affect both the FN400 familiarity effect and the parietal old/new recollection effect.

2.1. *Method*

2.1.1. *Subjects*

Thirty-eight right-handed students participated in the experiment for course credit. All subjects gave informed consent. Data from six subjects were discarded because of low accuracy ($n=2$), high impedances ($n=2$), excessive number of bad channels ($n=1$), or experimenter error in giving instructions ($n=1$). Of the 32 subjects analyzed there were 21 male and 11 female subjects ranging from 18 to 22 years old.

2.1.2. *Stimuli, design, and procedure*

Experiment 2 was identical to Experiment 1 with two exceptions. First, in each two-hour session, during the testing phase, EEG was recorded. Second, using their index finger of both hands, subjects pressed one key for studied and another for non-studied. Confidence ratings were not given at test because there were not enough trials to compute reliable ERPs within each confidence bin.

2.1.3. *EEG/ERP recording and analysis*

During the test phase of the experiment scalp voltages were collected with a 128-channel Geodesic Sensor Net™ (GSN 200 v. 2.1, Tucker, 1993) connected to an AC-coupled, 128-channel, high-input impedance amplifier (200 MΩ, Net Amps TM, Electrical Geodesics Inc., Eugene, OR). Amplified analog voltages (0.1–100 Hz bandpass) were digitized at 250 Hz. Individual sensors were adjusted until impedances were less than 50 kΩ.

The EEG was baseline corrected to a 100 ms pre-stimulus recording interval and digitally low-pass filtered at 40 Hz. Eye movements were corrected using an ocular artifact correction algorithm (Gratton et al., 1983). Individual channels were replaced on a trial-by-trial basis with a spherical spline algorithm (Srinivasan et al., 1996). Trials were discarded from analysis if accuracy was incorrect or more than 20% of the channels were bad (average amplitude over 100 μV or transit amplitude over 50 μV). EEG was measured with respect to a vertex reference (Cz), but an average-reference transformation was used to minimize the effects of reference-site activity and accurately estimate the scalp topography of the measured electrical fields (Dien, 1998). The average reference was corrected for the polar average reference effect (Junghofer et al., 1999).

2.2. Results

2.2.1. *Behavioral results*

Analyses were performed on discrimination (d') and response bias (c). Because there was no font match for new words, hits were compared to a common FA rate, as in Experiment 1. In the few instances when the hit rate was 1.0, the hit rate was adjusted to $1-1/(2N)$ (where N equals the number of old trials) to avoid an infinite d' (MacMillan and Creelman, 1991). d' and c were analyzed with a task × font fan × font match repeated measures ANOVA[2].

Table 3 shows the behavioral results from Experiment 2, which replicated the results from Experiment 1. Discrimination (d') was higher following the pleasantness (M $d'=1.68$) than the legibility task (M $d'=0.97$) ($F(1,31)=56.09$, $MSE=0.58$, $p<0.01$) for low (M $d'=1.38$) than high font fan words (M $d'=1.28$) ($F(1,31)=5.42$, $MSE=0.11$, $p=0.03$), and for matched (M $d'=1.51$) than non-matched font words (M $d'=1.15$) ($F(1,31)=162.53$, $MSE=0.05$, $p<0.01$). Task interacted with font fan such that the difference between low and high font fan words was greater following the legibility than the pleasantness task[2] ($F(1,31)=13.54$, $MSE=0.04$, $p<0.01$). The difference between low and high font fan words was significant only following the legibility task ($F(1,31)=28.50$, $MSE=1.12$, $p<0.01$). Font fan interacted with font match such that the difference between matched and non-matched font words was greater for low than high font fan words ($F(1,31)=19.84$, $MSE=0.02$, $p<0.01$). The difference between matched and non-matched font words was significant for both low ($F(1,31)=264.45$, $MSE=6.28$, $p<0.01$) and high font fan words ($F(1,31)=99.27$, $MSE=2.36$, $p<0.01$).

Response bias (c) was more conservative following the legibility (M $c=0.12$) than the pleasantness task (M $c=0.04$) ($F(1,31)=4.23$, $MSE=0.10$, $p=0.05$), for low (M $c=0.15$) than high font fan words (M $c=0.01$) ($F(1,31)=38.03$, $MSE=0.03$, $p<0.01$), and for non-matched (M $c=0.17$) than matched font words (M $c=-0.01$) ($F(1,31)=162.48$, $MSE=0.01$, $p<0.01$). Font fan interacted with font match such that the difference between matched and non-matched font words was greater for low than high font fan words ($F(1,31)=19.85$, $MSE=0.006$, $p<0.01$). The difference between matched and non-matched font words was significant for both low ($F(1,31)=264.42$, $MSE=1.57$, $p<0.01$) and high font fan words ($F(1,31)=99.22$, $MSE=0.59$, $p<0.01$).

RTs on only correct trials were analyzed with a memory status × task × font fan repeated measures ANOVA (see Table 4). Memory status interacted with font fan such that the difference between low and high font fan words was greater for old than new words ($F(2,62)=4.37$, $MSE=2543$, $p=0.02$). When RTs for new words were analyzed alone with a task × font fan repeated measures ANOVA, there were no significant condition effects. When old words were analyzed alone with a task × font fan × font match repeated measures ANOVA, RTs were faster for high (M $RT=843$) than low font fan words (M $RT=857$) ($F(1,31)=5.08$, $MSE=2393$, $p=0.03$) and for matched (M $RT=835$) than non-matched font words (M $RT=865$) ($F(1,31)=13.58$, $MSE=4151$, $p<0.01$). Font fan interacted with font match such that the difference between matched and non-matched font words was greater for low than high font fan words ($F(1,31)=7.61$, $MSE=1811$, $p<0.01$). The difference between matched and non-matched font words was significant only for low font fan words ($F(1,31)=34.76$, $MSE=62961$, $p<0.01$).

Table 3 – Behavioral data from Experiment 2.

	Condition	Ple LF	Ple HF	Leg LF	Leg HF
Hit	Match	0.82 (0.02)	0.81 (0.02)	0.70 (0.02)	0.69 (0.02)
	Non-match	0.70 (0.02)	0.74 (0.02)	0.53 (0.02)	0.61 (0.02)
FA	Match Non-match	0.21 (0.03)	0.25 (0.02)	0.23 (0.03)	0.34 (0.03)
d′	Match	1.90 (0.12)	1.82 (0.14)	1.30 (0.09)	1.01 (0.09)
	Non-match	1.48 (0.11)	1.54 (0.12)	0.83 (0.07)	0.75 (0.07)
c	Match	−0.02 (0.06)	−0.07 (0.06)	0.10 (0.06)	−0.04 (0.06)
	Non-match	0.19 (0.05)	0.07 (0.06)	0.33 (0.06)	0.09 (0.06)

Note. Means with standard errors in parentheses. Ple = pleasantness, Leg = legibility, LF = low font fan, HF = high font fan.

Table 4 – Reaction time data from Experiment 2.

	Condition	Ple LF	Ple HF	Leg LF	Leg HF
RT	Match	830 (34)	831 (34)	839 (43)	840 (42)
	Non-match	873 (37)	848 (38)	885 (46)	852 (42)
	New	928 (48)	944 (52)	908 (45)	905 (49)

Note. Means with standard errors in parentheses. Ple = pleasantness, Leg = legibility, LF = low font fan, HF = high font fan.

[2] Analyses were also performed on discrimination (da) and response bias (ca) using a zROC slope of 0.88 from Experiment 1. Results were qualitatively similar to d′ and c.

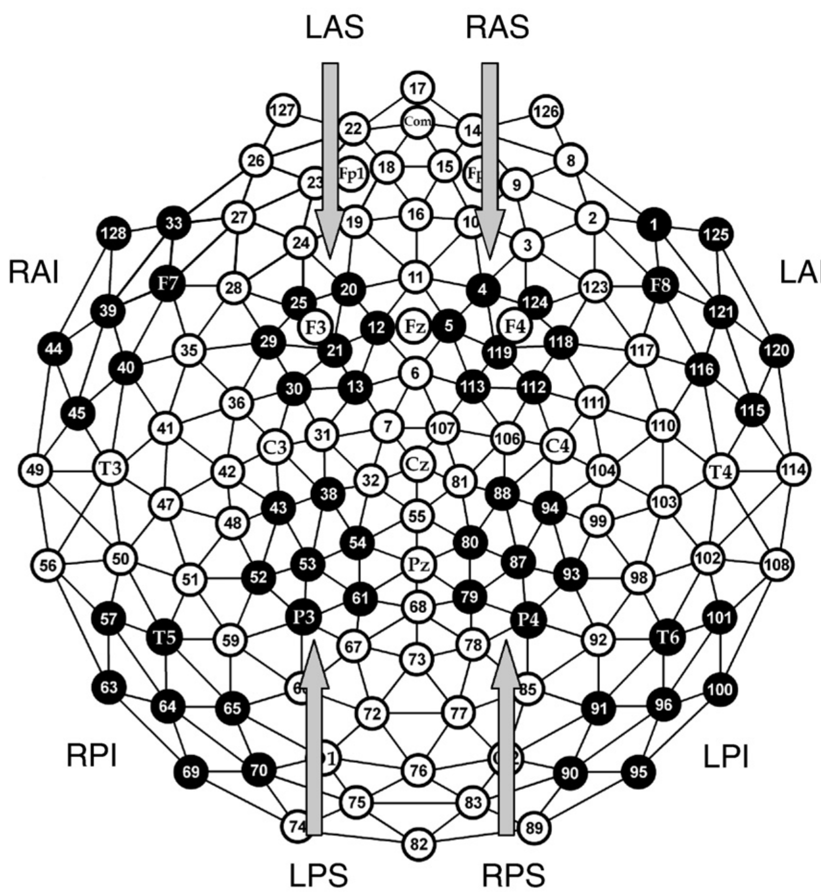

Fig. 1 – Geodesic sensor net layout. Electrode sites are numbered along with selected 10–10 positions. Black clusters are regions of interest (ROIs) included in analyses. L = left, R = right, A = anterior, P = posterior, I = inferior, and S = superior.

2.2.2. ERP results

Spatiotemporal regions of interest (ROIs) were defined according to previous research for both the FN400 and parietal old/new effects (Curran et al., 2006a). For the FN400 old/new effects, ROIs were the left and right anterior, superior channel groups (LAS and RAS shown in Fig. 1); mean amplitude from 300 to 500 ms was computed by averaging the channels within each region for each condition/subject. For the parietal old/new effects, ROIs were the left and right posterior, superior channel groups (LPS and RPS shown in Fig. 1); mean amplitude from 500 to 800 ms was computed by averaging the channels within each region for each condition/subject. Mean FN400 and parietal ERP amplitude values are shown in Table 5. Average waveforms are shown in Fig. 2, and topographic plots of the ERP old/new differences are shown in Fig. 5. Mean amplitudes were analyzed with a memory status × task × font fan × hemisphere (left, right) repeated measures ANOVA. Table 6 shows the significant results of these analyses. ANOVA results not reported were not significant.

2.2.2.1. FN400 effects. Memory status interacted with task such that the difference between old and new words was greater following the pleasantness than the legibility task (see Table 6 and Fig. 3A). For the pleasantness task, the difference between matched font and new words was significant ($F(1,31) = 43.53$, $MSE = 18.88$, $p < 0.01$) as well as the difference between non-matched font and new words ($F(1,31) = 24.19$, $MSE = 10.49$, $p < 0.01$). Following the legibility task, the difference between

Table 5 – ERP data from Experiment 2.

	Condition	Ple LF	Ple HF	Leg LF	Leg HF
FN400	Match	−0.78 (0.19)	−0.55 (0.20)	−0.46 (0.20)	−0.80 (0.21)
	Non-match	−0.90 (0.20)	−0.71 (0.17)	−0.94 (0.22)	−0.80 (0.19)
	New	−1.21 (0.17)	−1.21 (0.20)	−0.78 (0.19)	−0.81 (0.20)
Parietal	Match	1.24 (0.17)	1.10 (0.17)	1.30 (0.16)	1.10 (0.14)
	Non-match	1.30 (0.18)	1.33 (0.17)	1.05 (0.17)	1.08 (0.14)
	New	1.06 (0.14)	0.89 (0.18)	1.05 (0.13)	1.09 (0.14)

Note. Means with standard errors in parentheses. Ple = pleasantness, Leg = legibility, LF = low font fan, HF = high font fan.

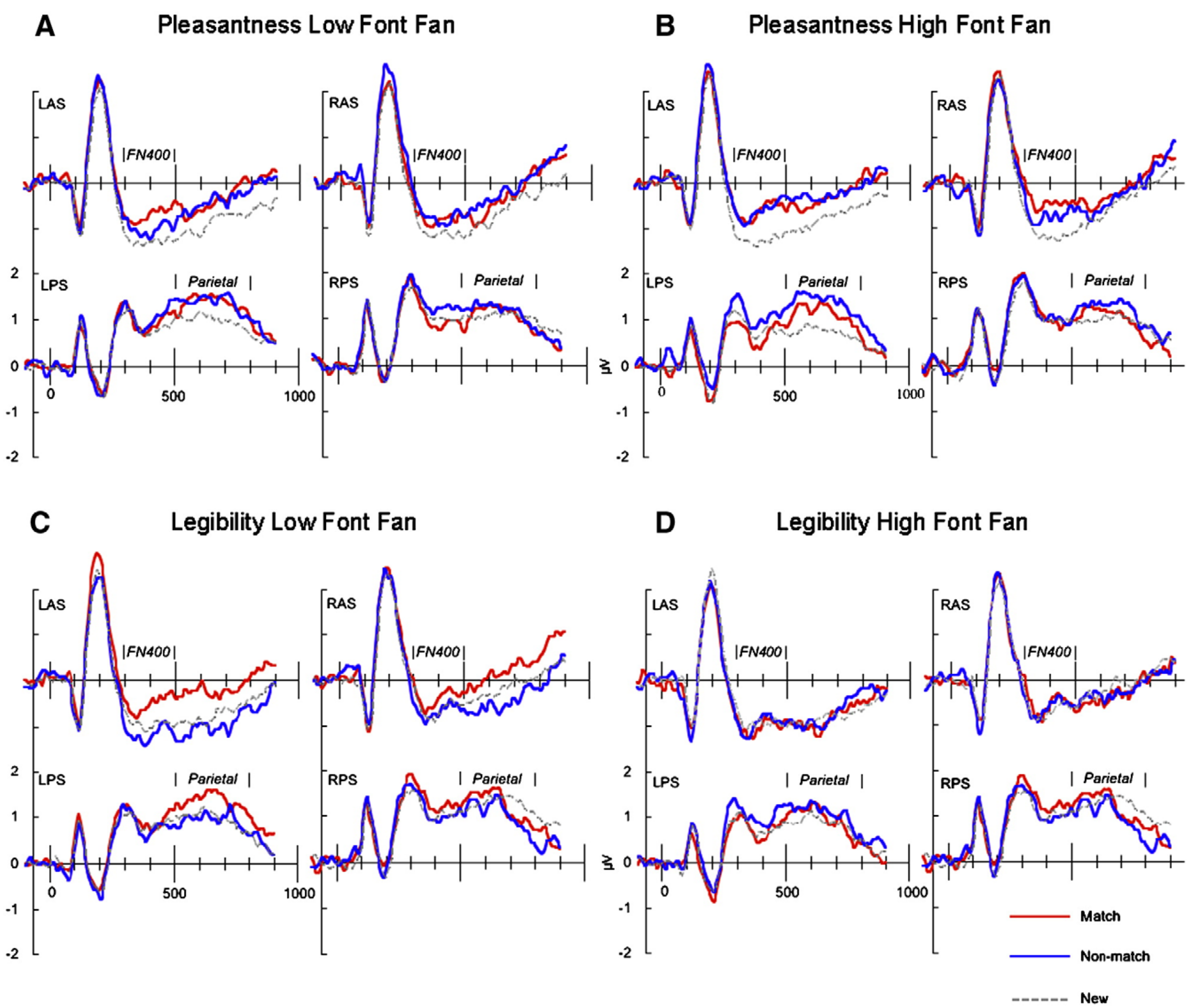

Fig. 2 – Average ERP waveforms for matched, non-matched font, and new words for the FN400 (LAS and RAS regions, 300–500 ms) and parietal old/new effect (LPS and RPS regions, 500–800 ms) for the pleasantness, low font fan condition (A), the pleasantness, high font fan condition (B), the legibility, low font fan condition (C), and the legibility, high font fan condition (D).

matched font and new words was significant ($F(1,31)=4.10$, $MSE=1.78$, $p=0.05$) as well as the difference between matched and non-matched font words ($F(1,31)=8.58$, $MSE=3.72$, $p<0.01$). There was an interaction between task and hemisphere such that the difference between the legibility and pleasantness task was greater in the right hemisphere.

There was a three-way interaction between memory status, font fan, and hemisphere such that the difference between matched and non-matched font words was greatest for low font fan words in the left hemisphere (see Table 6 and Fig. 3B). In the left hemisphere, the difference between matched font and new words was significant for both low ($F(1,31)=33.47$, $MSE=7.88$, $p<0.01$) and high font fan words ($F(1,31)=9.51$, $MSE=2.24$, $p<0.01$). Low font fan words differed between matched and non-matched font words ($F(1,31)=32.37$, $MSE=7.62$, $p<0.01$), but non-matched font and new words did not differ. High font fan words differed between non-matched font and new words ($F(1,31)=11.76$, $MSE=2.77$, $p<0.01$), but matched and non-matched font words did not differ. In the right hemisphere, the difference between matched font and new words was significant for both low ($F(1,31)=8.95$, $MSE=2.11$, $p<0.01$) and high font fan words

Table 6 – ERP ANOVA results from Experiment 2.

	Effect	F	MSE	p
FN400	Memory status	9.32	0.87	<0.01
	Memory status × task	9.40	0.43	<0.01
	Task× x hemisphere	4.90	0.71	0.03
	Memory status × font fan × hemisphere	5.95	0.24	<0.01
Parietal	Memory status	3.95	0.59	0.02
	Memory status × task	3.44	0.63	0.04
	Memory status × font fan × hemisphere	3.29	0.26	0.05

Note. ANOVA results not reported were not significant. Memory status = match, non-match, new, task = pleasantness, font fan = low, high, hemisphere = left, right.

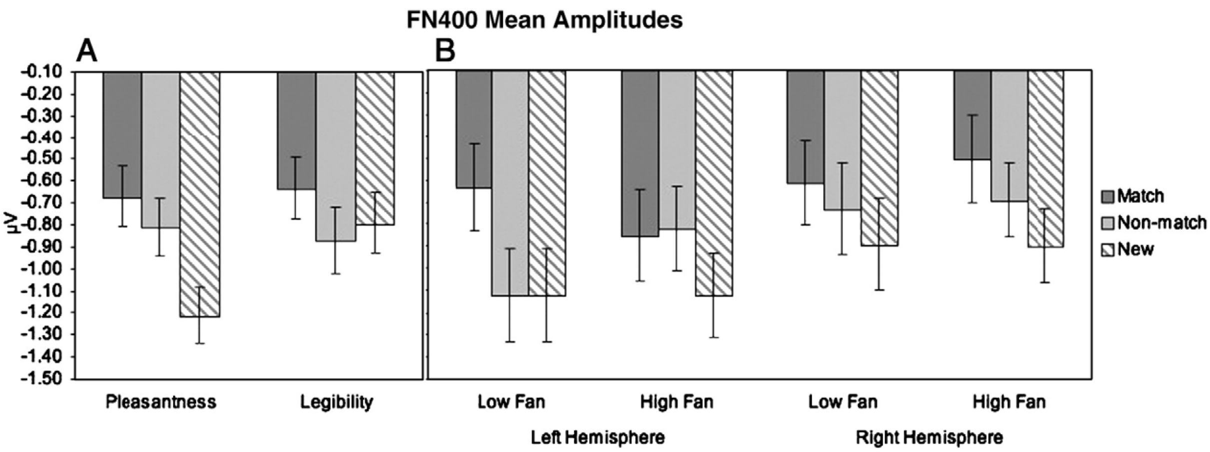

Fig. 3 – Mean amplitudes for the FN400 (LAS and RAS regions, 300–500 ms). Error bars are the standard errors of the mean. A) Memory status × task interaction. B) Memory status × font fan × hemisphere interaction.

($F(1,31)=21.94$, $MSE=5.17$, $p<0.01$). High font fan words differed between matched and non-matched font words ($F(1,31)=4.55$, $MSE=1.07$, $p=0.04$) and differed between non-matched font and new words ($F(1,31)=6.50$, $MSE=1.53$, $p=0.01$).

2.2.2.2. Parietal effects. Memory status interacted with task such that the difference between old and new words was greater following the pleasantness than the legibility task (see Table 6 and Fig. 4A). For the pleasantness task, the difference between matched font and new words was significant ($F(1,31)=3.98$, $MSE=2.52$, $p=0.05$) as well as the difference between non-matched font and new words ($F(1,31)=11.81$, $MSE=7.47$, $p<0.01$). Following the legibility task, there were no memory status effects.

There was a three-way interaction between memory status, font fan, and hemisphere such that the difference between matched and non-matched font words was greatest for low font fan words in the left hemisphere (see Table 6 and Fig. 4B). In the left hemisphere, the difference between matched font and new words was significant for both low ($F(1,31)=17.78$, $MSE=4.55$, $p<0.01$) and high font fan words ($F(1,31)=6.60$, $MSE=1.69$, $p=0.01$). Low font fan words differed between matched and non-matched font words ($F(1,31)=5.42$, $MSE=1.39$, $p=0.02$), but non-matched font and new words did not differ. High font fan words differed between matched and non-matched font words ($F(1,31)=5.38$, $MSE=1.38$, $p=0.02$) and differed between non-matched font and new words ($F(1,31)=23.89$, $MSE=6.11$, $p<0.01$). In the right hemisphere there were no significant condition differences.

2.2.2.3. Range normalized difference scores. Fig. 5 suggests that the 300–500 ms FN400 old/new differences are more anterior than the 500–800 ms parietal old/new differences. To consider the broader topography of the results, we calculated mean amplitudes for 8 electrode groups (see Fig. 1). Differences between old and new words were scaled using a range normalization method (McCarthy and Wood, 1985). Using this method, different scalp topographies can indicate different neuronal sources or the same sources with different distributions of source strengths. The range normalized difference scores were compared in a time (300–500 ms/500–800 ms) × task × font fan × font match × superior/inferior × anterior/posterior × hemisphere repeated measures ANOVA. To focus on the distinct topography of the FN400 and parietal old/new effects, we only report effects that interacted with time and location.

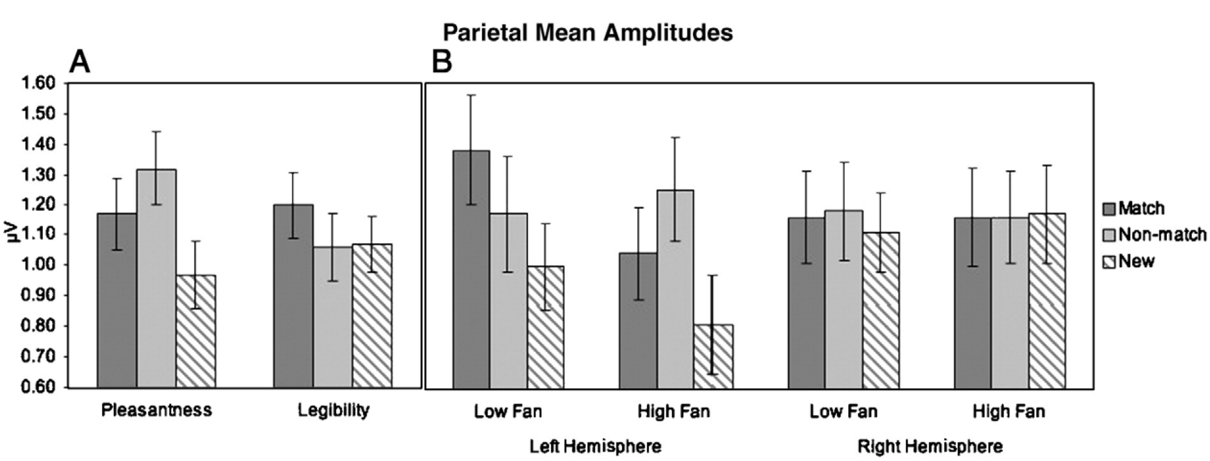

Fig. 4 – Mean amplitudes for the parietal old/new effect (LPS and RPS regions, 500–800 ms). Error bars are the standard errors of the mean. A) Memory status × task interaction. B) Memory status × font fan × hemisphere interaction.

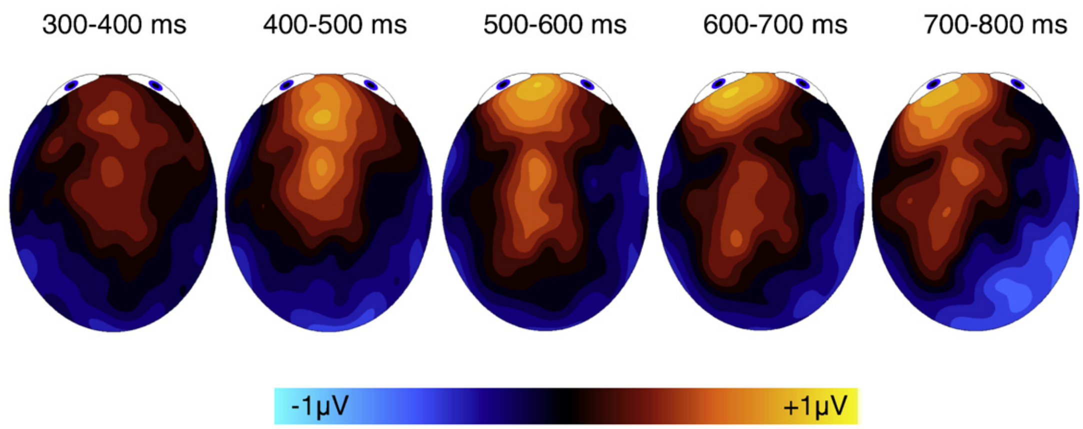

Fig. 5 – Topographic plots of old/new differences, collapsed across task, fan, and perceptual match, from 300 to 800 ms in 100 ms intervals.

There was an interaction between time and hemisphere ($F(1,31)=5.19$, $MSE=4.07$, $p=0.03$) such that old/new differences were more positive over the left than the right hemisphere for the parietal old/new effect time window but similar across both hemispheres for the FN400 time window. There was an interaction between time, superior/inferior, anterior/posterior, and hemisphere ($F(1,31)=4.72$, $MSE=0.34$, $p=0.04$) such that old/new differences were more positive over the anterior than the posterior regions for the FN400 time window, but amplitudes were more positive over posterior than anterior regions for the parietal old/new effect time window in the left hemisphere.

This more anterior distribution from 300 to 500 ms and more posterior distribution from 500 to 800 ms are consistent with our *a priori* selected frontal ROIs for the FN400 effect and posterior ROIs for the parietal old/new effect. The left lateralization of the parietal old/new effects is consistent with previous studies (Curran et al., 2006b; Rugg and Curran, 2007).

2.3. Discussion

The behavioral results from Experiment 2 replicated those of Experiment 1, except that overall response bias was more conservative in Experiment 2. It is possible that subjects set their threshold higher for "old" responses when they had to commit to either "old" or "new" responses rather than giving a range of confidence responses as in Experiment 1. As discussed previously, the present results mostly replicated those of Reder et al.'s (2002) Experiment 2. Like in Reder et al.'s (2002) Experiment 2, subjects' discrimination was better following the pleasantness task than the legibility task and for words that perceptually matched from study to test, but perceptual matching was enhanced for low font fan words. Also, similar to a non-significant trend toward greater differences between low and high font fan words following the legibility task in Reder et al.'s (2002) Experiment 2, the present experiments found a font fan effect that was only significant following the legibility task.

As in Experiment 1, RT results were generally consistent with accuracy in that old conditions with higher accuracy had faster reaction times, except for the font fan effect which was more accurate yet slower for low than high font fan words.

The ERP results from Experiment 2 showed similar memory status × task and memory status × font fan × hemisphere interactions for the FN400 and the parietal old/new effects. For the FN400, following the pleasantness task and for high font fan words in the left hemisphere, matched and non-matched font words had more positive amplitudes than new words. In contrast, following the legibility task and for low font fan words in the left hemisphere, matched font words had more positive amplitudes than non-matched font and new words. The parietal old/new effect showed similar results to the FN400 except that words studied with the legibility task did not show any effect of memory status. These ERP results correspond to the behavioral results. The larger old/new effects following the pleasantness task correspond to higher discrimination for the semantic task. The lack of a memory status effect following the legibility task corresponds to lower discrimination for the perceptual task. The similarity between non-matched font and new words in some conditions (legibility and low fan) for the FN400 and the parietal old/new effect also correspond to low discrimination in these conditions. Although these conditions showed low levels of discrimination, subjects were able to recognize the words. It is possible that they were relying on other processes to recognize the words that are not represented in the ERP components studied. The ERP results indicate that both familiarity and recollection are sensitive to LOP and perceptual match when the perceptual information is distinctive. In addition, analyses of range normalized difference scores showed that old/new differences were more positive over bilateral anterior than posterior regions for the FN400 between 300 and 500 ms, but amplitudes were more positive over left posterior than anterior regions for the parietal old/new effect between 500 and 800 ms. These results indicate that the FN400 and parietal old/new effect represent spatiotemporally dissociable processes that happen to be similarly affected by the present manipulations.

3. General discussion

The purpose of the present experiments was to determine how factors such as encoding task and perceptual match contribute to recognition memory. In order to resolve previous conflicting results regarding LOP effects, we had subjects do different encoding tasks on separate days. In Experiments 1 and 2, discrimination was better following the pleasantness (semantic) than the legibility (perceptual) encoding task. In Experiment 2, amplitude differences between old and new words were greater following the pleasantness than the legibility task for the FN400 and parietal old/new ERP effects. In order to resolve previous conflicting results regarding perceptual match effects, we manipulated the distinctiveness of fonts. In Experiments 1 and 2, discrimination was better for matched than non-matched font words and this perceptual matching effect was greater for low font fan words (higher distinctiveness). In Experiment 2, left hemisphere amplitude differences between matched and non-matched font words were greater for low font fan than high font fan words for the FN400 and parietal old/new ERP effects. Combined these results suggest that semantic encoding task and perceptual match for distinctive items aid recognition memory by acting on both familiarity and recollection processes, as indexed by the FN400 and parietal old/new effects.

The semantic encoding effects were in accord with LOP (Craik and Lockhart, 1972; Craik and Tulving, 1975) in showing that discrimination was greater following the pleasantness task in which words were encoded more semantically than following the legibility task where words were encoded more perceptually. The ERP results showing greater FN400 and parietal old/new differences following the semantic compared to the perceptual encoding task are consistent with behavioral and ERP studies showing that LOP affects both familiarity and recollection processes (Rugg et al., 2000; Yonelinas, 2001), but inconsistent with ERP studies showing that LOP affects only recollection processes (Paller and Kutas, 1992; Rugg et al., 1998). Rugg et al. (2000) manipulated LOP across blocks and found ERP differences between old and new words diverging between shallow and deep encoding conditions as early as 300 ms. It is possible that blocking encoding conditions, or in the present case separating them into sessions, enhances these effects. Rugg et al. (1998) intermixed LOP within blocks and found greater ERP differences between old and new words following the deeper encoding condition after approximately 500 ms. It is possible that mixing shallow and deep encoding conditions weakened the LOP effect. The present results suggest that LOP affects recognition by influencing both familiarity and recollection processes.

Discrimination was better for matched than non-matched font words, and this perceptual match effect was greater for low font fan words. The ERP results showing greater amplitude differences between matched and non-matched font words for low than high font fan words for the FN400 and parietal old/new ERP effects are consistent with studies showing that perceptual match can affect both familiarity and recollection processes (Ecker et al., 2007a; Groh-Bordin et al., 2006), but inconsistent with previous studies showing perceptual match effects specific to familiarity (Ally and Budson, 2007; Curran and Doyle, submitted; Schloerscheidt and Rugg, 2004) or recollection processes (Hirshman et al., 1999; Reder et al., 2002). Ecker et al. (2007a) and Groh-Bordin et al. (2006) have shown perceptual match effects by manipulating picture color. Ecker et al. (2007a) described their results by postulating differences in processing between intrinsic information (within-item features of an object such as color) and extrinsic information (context). According to their theory intrinsic information is bound in object tokens that are automatically retrieved and therefore affect both familiarity and recollection processes. The results of the present study are in general agreement with Ecker et al.'s (2007a) theory because font changes are intrinsic, but font information may not be automatically retrieved. Word–font associations may have been automatically encoded, but at test subjects were consciously aware of font variation and could use font information to guide retrieval. The RT results showing slower responses to low than high font fan words suggest that subjects may have strategically used font information to retrieve low font fan words. In addition, the RT results from Experiment 1 showing a task × fan interaction suggest that subjects were strategically using font fan information to retrieve low font fan words especially when memory was poor following the legibility task. In addition, the present results extend their findings (Ecker et al., 2007a; Groh-Bordin et al., 2006) to words with an intrinsic font feature and by showing that intrinsic perceptual match effects are enhanced when the matching feature is distinctive. These results also relate to studies on associative recognition. Recent studies have examined the processes involved in recognizing the association of two items. Although it has been assumed that associative recognition depends on recollection, some studies have shown that familiarity can support associative recognition when individual item representations can be unitized into a single representation (Caldwell and Masson, 2001; Quamme et al., 2007; Speer and Curran, 2007; Yonelinas et al., 1999). The present results extend these findings by suggesting that in addition to unitization of items, unitization of items and distinctive intrinsic features can lead to familiarity supporting associative recognition.

Some studies have found that perceptual match affects only familiarity processes (Ally and Budson, 2007; Curran and Doyle, submitted; Schloerscheidt and Rugg, 2004). It is possible that using pictures masks the effects of perceptual match. Hirshman et al. (1999) found that perceptual match affects only recollection processes. It is possible that Hirshman et al. (1999) did not find perceptual match effects for familiarity and recollection because the perceptual information was not distinctive (i.e., visual/auditory modalities have a high fan when each are associated with half the studied words). Similarly, Curran and Dien (2003) failed to find significant perceptual match effects on either the FN400 or parietal effects with a similar study/test modality paradigm in which half the words were presented visually and half were presented aurally. Reder et al.'s (2002) Experiment 3 found that distinctiveness enhanced recollection; but, as stated previously, re-analysis of their results suggest that familiarity was also greater for distinctive words. The present results extend these findings by showing that, for words, distinctiveness enhances perceptual match effects by acting on the FN400 and the parietal old/new effect. Therefore, the present results add additional support for suggesting that perceptual information may influence recognition memory by contributing to both familiarity and recollection processes.

Although there is general agreement that the FN400 and parietal old/new effect represent dissociable neural components (reviewed in Rugg and Curran, 2007), there is some disagreement about which memory processes these neural components represent. In the present study there was a spatiotemporal dissociation between ERP components such that old/new differences were more positive over the anterior than the posterior regions for the FN400 between 300 and 500 ms but more positive over posterior than anterior regions for the parietal old/new effect between 500 and 800 ms. It was assumed that the FN400 indexes familiarity and the parietal old/new effect indexes recollection, but the relationship between these ERP components and processes has been debated.

An alternative hypothesis is that the FN400 indexes a form of implicit memory, conceptual priming (Paller et al., 2007; Voss and Paller, 2006; Yovel and Paller, 2004). Conceptual priming is a form of repetition priming in which semantic information is repeated. There may be some overlap between conceptual priming and familiarity (e.g., Yonelinas, 2002), and it is therefore difficult to separate out the contribution of conceptual priming and familiarity to the FN400 component. But the present Experiment 2 adds to previous studies showing that perceptual match modulates the FN400, and indicate that the FN400 is affected by both conceptual and perceptual information (Ally and Budson, 2007; Curran and Dien, 2003; Curran and Doyle, submitted; Ecker et al., 2007a, 2007b; Groh-Bordin et al., 2006; Schloerscheidt and Rugg, 2004). Therefore, this evidence suggests that the conceptual priming account of the FN400 is too limited. Rather it is likely that the FN400 represents familiarity, which can include both conceptual and perceptual contributions.

In addition to the debate about the relationship of the FN400 to familiarity, some have argued that the parietal old/new effect represents decisional factors rather than recollection. Finnigan et al. (2002) showed that the FN400 was sensitive to the strength of studied items, but the parietal old/new effect was sensitive to the accuracy of responses, or decisional factors. They suggested that a single familiarity process is sufficient for recognition for single item recognition tasks, but they also noted the possibility of an additional recollection process being involved in more complex recognition tasks that require memory for details such as study plurality or source. However, Woodruff et al. (2006) found that the FN400 differentiates confident from not confident remembered items, but the parietal old/new effect differentiates items recollected with specific details of the study episode and highly confident old responses without recollection of specific details of the study episode. These results indicate that recollection is unique and does not only represent a high confidence response (see also Curran, 2004). Therefore, it seems likely that the FN400 and parietal old/new effect index familiarity and recollection, rather than conceptual priming and decisional factors.

4. Conclusions

The present experiments demonstrate that semantic and perceptual information can aid recognition memory. Recognition memory is better when subjects are oriented to pay attention to semantic information at encoding, and perceptual information can aid recognition when that information is distinct. The present experiments showed that semantic and perceptual information for distinctive items can contribute to recognition memory by acting on both familiarity and recollection processes.

Acknowledgments

This work was supported by NIH grant MH64812 and NSF grant #SBE-0542013 to the Temporal Dynamics of Learning Center, an NSF Scence of Learning Center. We thank Casey DeBuse and Brion Woroch for help with experiment programming, Kristen Becker, Alexis Billings, Christopher Bird, Jeanne Doyle, Tessa Hill, Megan Lipsett, Jessica Pachter, and Brent Young for subject testing, and Simon Dennis for comments on an earlier draft.
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