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An ERP investigation into the strategic regulation of the fluency heuristic during recognition memory

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Abstract

The goal of the present study was to determine whether masked repetition priming affects *ERPs* differently depending on whether or not participants are biased by task conditions to interpret enhanced perceptual fluency as evidence of prior study. Participants studied a list of words either in the visual modality or in the auditory modality and then performed a visual recognition memory test while *ERPs* were recorded. During the test, half the stimuli were preceded by a briefly presented matching prime word and half were preceded by a briefly presented non-matching prime word. Unlike in previous behavioral studies, masked repetition priming led to a reduction in positive recognition responses following auditory study, and had no effect following visual study, although post hoc analyses suggest that participants who received the visual study list may have relied on fluency to make some of their recognition decisions. Masked repetition priming also led to positive *ERPs* during two time windows – an early 300–500ms window and a later 500–700ms window. During the later time window, masked repetition priming exhibited a frontal scalp distribution that was most pronounced for participants who received the auditory study list. We suggest that this late frontal effect reflects participants' tendency to reject enhanced perceptual fluency as evidence of prior study.

Keywords

recognition memory; decision-making; fluency heuristic; familiarity; event-related potential

1. Introduction

The ability to discriminate between familiar and novel stimuli is a fundamental aspect of memory, and in the last decade there has been considerable interest in understanding the processes and types of information that support recognition memory. In a standard recognition memory experiment, participants are given a study list of stimuli (e.g., words or pictures) followed by a test comprised of targets (studied items) and lures (unstudied items), and their task is to report whether each test stimulus appeared on the earlier study list, usually by making a dichotomous “yes/no” judgment. According to most accounts,

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recognition memory decisions are based on two processes called *familiarity* and *recollection* (Jacoby, 1991; Mandler, 1980; for a review, see Yonelinas, 2002). Familiarity is a fast, seemingly automatic process that promotes feelings of undifferentiated recency, whereas recollection is a slower, more consciously controlled process that permits retrieval of information about prior context. There is considerable evidence that supports this general dual-process framework. For example, measures of recollection and familiarity have been dissociated by a number of encoding and retrieval manipulations, including levels of processing (Gardiner, 1988; Yonelinas, Kroll, Dobbins, Lazzara, & Knight, 1998), divided attention (Gruppuso, Lindsay, & Kelley, 1997; Gardiner & Parkin, 1990; Yonelinas, 2001), speeded responding (Benjamin & Craik, 2001; Yonelinas & Jacoby, 1994), perceptual matching (Rajaram, 1996), and shifting response criteria (Yonelinas, 2001; Strack & Foerster, 1995; Gardiner, Richardson-Klavehn, & Ramponi, 1997; Postma, 1999). Moreover, recollection and familiarity seem to depend on mostly distinct underlying brain regions. Recollection depends mainly on activity in the hippocampus, whereas familiarity depends mainly on activity in the perirhinal and entorhinal cortices of the medial temporal lobe (Aggleton & Brown, 2006; Davachi, Mitchell, & Wagner, 2003; Bowles et al., 2007, 2010; Eichenbaum, Yonelinas, & Ranganath, 2007; Norman & O'Reilly, 2003; Wolk et al., 2010). Studies in which event-related potential (ERPs) have been recorded also provide evidence supporting dual-process theory. Familiarity is thought to be associated with a frontally distributed positivity for hits (correct responses to targets) vs. correct rejections (correct responses to lures) around 300–500ms following stimulus onset (referred to as the *FN400*), whereas recollection is thought to be associated with a more parietal-focused positivity for hits vs. correct rejections around 500–700ms (referred to as the *late parietal complex [LPC]*; for a review, see Rugg & Curran, 2007).

In addition to these retrieval processes, recognition memory decisions are influenced by heuristics, biases, and decision strategies. One heuristic in particular that has been extensively studied is the *fluency heuristic*, which refers to the tendency for people to base old/new recognition decisions on the relative ease with which a stimulus is processed (Jacoby & Dallas, 1981; Whittlesea & Williams, 2000). Although fluency and familiarity are associated with distinct patterns of neural activity (Nessler et al., 2005; Woollams et al., 2008), people occasionally interpret processing fluency as evidence of stimulus familiarity (Kinoshita, 1997; Rajaram, 1993). This likely occurs because repeated stimuli are generally processed more easily than non-repeated stimuli (due to the phenomenon of *repetition priming*). People presumably become sensitive to this correlation overtime, which makes the fluency heuristic a generally effective basis for recognition decisions (Unkelbach, 2006). However, illusions of recognition can occur when fluency arises from a source other than prior study. For instance, people are more likely to claim to recognize test stimuli that appear in high contrast relative to stimuli that appear in low contrast (Unkelbach, 2006). People are also more likely to claim to recognize test words that are preceded by a briefly presented matching prime word than those that are preceded by a briefly presented non-matching prime word (hereafter referred to as *masked repetition priming*; Jacoby & Whitehouse, 1989; Westerman, 2001).

Although people seem to exhibit a bias towards fluently processed stimuli under many circumstances, a considerable body of work suggests that people use the fluency heuristic in a fairly sophisticated way. Indeed, people's decisions about whether to rely on fluency during recognition seem to be guided by post-retrieval processes and metacognitive knowledge. For instance, people take into account the level of fluency associated with other stimuli in the environment when deciding whether to attribute fluency to prior study (Kleider et al., 2004; Westerman, 2008). Moreover, people discount fluency as evidence of prior study when they realize that there could be another explanation besides prior study for why some test stimuli seem easier to process than others (Whittlesea et al., 1990). People

also refrain from using the fluency heuristic when it seems unlikely that enhanced fluency is diagnostic of prior study (Westerman et al., 2002, 2003). Specifically, when participants receive an auditory study list of words followed by a visual recognition test, masked repetition priming has little or no effect on old/new recognition decisions. This is true even when participants are given a “counterfeit study list” comprised of visual or auditory noise and led to believe that they were given a subliminal study list of visual or auditory words, respectively (Westerman et al., 2002). Similar results occur when participants are led to believe they were given a “subliminal” study list comprised of pictures prior to a visual test comprised of words (Westerman et al., 2003). These findings suggest that people do not automatically base recognition decisions on an assessment of processing fluency. Rather, people use the fluency heuristic in a fairly sophisticated and strategic way by relying on metacognitive knowledge about the circumstances under which fluency is diagnostic of prior study.

Very few studies have investigated the neural activity associated with the attributional processes that are presumed to underlie the fluency heuristic. However, in one study (Wolk et al., 2004) participants performed a recognition memory test while *ERPs* were recorded, and conceptual fluency was manipulated at test with the use of predictive and neutral sentence stems. Consistent with the results of other studies that have used this paradigm (e.g., Kurilla & Westerman, 2008; Whittlesea & Williams, 2001), participants were more likely to claim to recognize test words (e.g., Boat) that were preceded by predictive sentence stems (e.g., “The stormy sea tossed the...”) compared to test words that were preceded by neutral or non-predictive sentence stems (e.g., “She saved up her money and bought a ...”). More importantly, test words preceded by predictive stems and classified as “unstudied” on the test were associated with late, positive *ERPs* over prefrontal cortex – an area of the brain that has been linked to post-retrieval monitoring (Nolde et al., 1998a b; Ranganath & Paller, 1999). Furthermore, the magnitude of this late frontal positivity was negatively correlated with people’s tendency to claim to recognize test items that were preceded by predictive stems, suggesting that this frontal activation reflected people’s tendency to reject enhanced conceptual fluency as evidence of prior study.

It is presently unknown whether the neural activity that underlies attribution of perceptual fluency is similar to that which underlies attribution of conceptual fluency, as described above. Previous *ERP* studies have shown that enhanced perceptual fluency is associated with centro-parietal positivity that peaks around 300–500ms following stimulus onset (Nessler et al., 2005; Woollams et al., 2008). However, these studies did not attempt to manipulate participants’ attributions of fluency, so it is somewhat unclear what this pattern of activity reflects. Given that masked repetition priming leads to positive *ERPs* in the 300–500ms time window regardless of whether participants are engaged in a recognition memory task (Misra & Holcomb, 2003; Woollams et al., 2008), it is possible that this enhanced positivity might simply reflect an individual’s experience of fluency rather than their attribution of fluency to a particular source. If the late frontal positivity reported by Wolk et al. (2004) reflects fluency attribution (i.e., attribution of fluency to some source other than prior study), then it should be possible to elicit frontal positivity even when perceptual fluency is manipulated, provided participants are subtly discouraged from attributing enhanced fluency to prior study.

The goal of the present study, therefore, was to determine whether enhanced perceptual fluency leads to a different pattern of neural activity depending on whether participants regard enhanced perceptual fluency as evidence of prior study. To do this, we sought to capitalize on the finding that people are reluctant to attribute enhanced perceptual fluency to prior study following a change in sensory modality between study and test (Westerman et al., 2002). Participants were randomly assigned to receive either a visual or an auditory

study list of words. Following the study phase, both groups were given the exact same visual recognition memory test while *ERPs* were recorded. Half the test items were preceded by a matching prime word and half were preceded by a non-matching prime word. We predicted that masked repetition priming would elevate positive recognition decisions following visual study but not following auditory study because people should disregard enhanced perceptual fluency as evidence of prior study following auditory study (Westerman et al., 2002). More importantly, if late positive *ERPs* over frontal recording areas reflect a tendency to discount fluency, as suggested by the findings of Wolk et al. (2004), then masked repetition priming should lead to late frontal positivity following auditory study but not following visual study.

2. Results

2.1 Behavioral results

Signal detection estimates of discrimination (d') and criterion placement (C) are shown in Table 1. A 2 (prime type: matching vs. non-matching) $\times$ 2 (group: visual study vs. auditory study) mixed analysis of variance (*ANOVA*) on d' scores revealed that there were no main effects or interactions (all F 's < 1), suggesting that neither the sensory modality of the study phase nor the priming manipulation affected recognition accuracy. Analysis of criterion placement also revealed no main effects or interactions [$F(1, 38) = 3.25$, $MSE = .03$, $\eta^2 = .08$, $p = .08$, for the main effect of prime type, and $F < 1$ for both the main effect of group and the prime type $\times$ group interaction]. However, follow up analyses performed separately on each group revealed that priming led to conservative responding following auditory study, $F(1, 19) = 4.45$, $MSE = .02$, $\eta^2 = .19$, $p = .05$, but had no effect on response bias following visual study, $F < 1$.

Hits and false alarms and associated reaction times for each condition are shown in Tables 2 and 3, respectively. A 2 (test item status) $\times$ 2 (prime type) $\times$ 2 (group) mixed *ANOVA* carried out on positive recognition responses revealed that there was a main effect of test item status only, $F(1, 38) = 178.88$, $MSE = .05$, $\eta^2 = .83$, $p < .001$. Not surprisingly, participants were more likely to claim to recognize studied than unstudied words. Priming had no effect on recognition decisions in either the visual study group, $F < 1$, or the auditory study group, $F(1, 19) = 2.99$, $MSE = .01$, $\eta^2 = .14$, $p = .10$, and there was no prime type $\times$ group interaction, $F(1, 38) = 1.56$, $MSE = .01$, $\eta^2 = .04$, $p = .22$. Although the lack of prime type $\times$ group interaction was surprising, closer inspection revealed that one participant in the auditory study group exhibited a priming effect that was 2.6 standard deviations above the mean for that group. When this participant was excluded from the analysis the prime type $\times$ group interaction approached significance, $F(1, 37) = 3.22$, $MSE = .004$, $\eta^2 = .08$, $p = .08$. Consistent with the analysis of criterion placement reported above, participants who received the auditory study list were *less likely* to claim to recognize test words preceded by matching primes compared to test words preceded by non-matching primes, $F(1, 18) = 7.88$, $MSE = .003$, $\eta^2 = .30$, $p = .01$. Thus, priming had no effect on positive recognition responses following visual study, and it led to a slight reduction in positive recognition responses following auditory study. Although this pattern of results differs from our original prediction, it is nonetheless consistent with the claim that people adopt different interpretations of enhanced perceptual fluency following visual and auditory study.¹ Later we discuss why priming might have failed to affect recognition decisions following visual study.

¹Given that our goal was to compare two groups of people with different interpretations of fluency, the participant who exhibited a priming effect that was 2.6 standard deviations above the mean for the auditory group was excluded from all subsequent statistical analyses. The exclusion of this participant did not change the results of any other comparisons. Furthermore, inspection of the priming effect for each individual in the visual study group revealed that there were no outliers in that group.

A second $2 \times 2 \times 2$ ANOVA was performed on RTs from each condition. This revealed main effects of test item status, $F(1, 37) = 59.59$, $MSE = 20162.52$, $\eta^2 = .57$, $p < .001$, and prime type, $F(1, 37) = 61.21$, $MSE = 13186.08$, $\eta^2 = .62$, $p < .001$. Participants responded more quickly to studied words than to unstudied words. They also responded more quickly to test items preceded by matching primes than to test items preceded by non-matching primes. There was also an interaction between test item status and prime type, $F(1, 37) = 31.41$, $MSE = 4994.97$, $\eta^2 = .46$, $p < .001$, such that priming led to a larger reduction in RTs for studied words than for unstudied words. No other interactions were significant.

2.2 ERP results

Based on previous studies that have examined the ERP correlates of familiarity, recollection, and perceptual fluency, we selected a priori time windows of 300–500ms and 500–700ms post stimulus onset. In each time window, we conducted a 2 (test item status) $\times 2$ (prime type) $\times 2$ (group) $\times 62$ (Channel) mixed ANOVA on mean amplitudes using the Greenhouse-Geisser correction for nonsphericity.² Three participants in the visual study group were excluded for having fewer than 20 artifact free trials in one or more conditions of interest. The resulting trial counts were as follows (mean, range): hits preceded by matching primes (60.32; 25 – 98), hits preceded by non-matching primes (60.22; 24 – 96), CRs preceded by matching primes (59.68; 21 – 97), CRs preceded by non-matching primes (59; 22 – 90).

300–500 msec—The omnibus ANOVA revealed interactions between test item status and channel, $F(4.86, 165.30) = 6.80$, $MSE = 10.49$, $\eta^2 = .17$, $p < .001$, and between prime type and channel, $F(3.49, 118.63) = 22.04$, $MSE = 29.08$, $\eta^2 = .39$, $p < .001$. No other interactions were significant. Figure 1 shows the ERPs recorded from channel Cz for studied and unstudied items. As typically observed, ERPs for hits were more positive than those for CRs, and this was most prominent over central scalp sites (hereafter, we refer to this as the old/new effect). Figure 2 shows the ERPs recorded from channel Cz for studied and unstudied items that were preceded by either matching or non-matching primes. ERPs for items preceded by matching primes were more positive than those for items preceded by non-matching primes, and this was also most prominent over central and posterior scalp sites.

We next compared the scalp distribution of the old/new effect with that of the masked repetition priming effect using the scaling procedure described by McCarthy and Wood (1985). This revealed no interactions, suggesting that the topography of the old/new effect did not differ from the topography of the masked repetition priming effect, $F < 1$. Furthermore, the topography of neither effect differed between groups [$F < 1$ for the old/new effect, and $F(3.44, 116.90) = 1.59$, $MSE = .07$, $\eta^2 = .05$, $p = .19$ for the masked repetition priming effect]. Thus, the data from the 300–500ms time window largely replicate prior findings in showing that ERPs were more positive for hits relative to CRs and for items that were preceded by matching primes relative to items that were preceded by non-matching primes.

500–700 msec—The omnibus ANOVA revealed significant interactions between test item status and channel, $F(4.96, 168.49) = 6.46$, $MSE = 15.92$, $\eta^2 = .16$, $p < .001$, and between prime type and channel, $F(3.84, 130.38) = 10.22$, $MSE = 24.30$, $\eta^2 = .23$, $p < .001$. As in the earlier time window, ERPs were more positive for hits than for CRs (see Figure 1), and for items that were preceded by matching primes than for items that were preceded by non-matching primes. Importantly, there was also a significant interaction between test item

²Sixty-two channels were included instead of 64 because one electrode (P9) broke during data collection. As such, data recorded from P9 and P10 were discarded prior to analysis.

status and prime type, $F(1, 34) = 6.01$, $MSE = 134.51$, $\eta^2 = .15$, $p = .02$, such that the magnitude of the masked repetition priming effect on *ERPs* was larger for CRs than for hits. Given that participants must reject enhanced fluency as evidence of prior study in order to correctly classify unstudied words, this relatively late positivity might reflect people's tendency to reject perceptual fluency as a basis for old/new recognition. Consistent with this claim is the fact that priming led to enhanced positivity mainly over frontal recording sites during the 500–700ms time window, which can be seen in Figure 3. Unlike in the earlier time window, the scalp distribution of the masked repetition priming effect was different from that of the old/new effect, which was more central, $F(3.86, 131.13) = 4.39$, $MSE = .03$, $\eta^2 = .11$, $p < .01$. Furthermore, as can be seen in a comparison of Figures 2 and 3, the scalp distribution of the masked repetition priming effect was more frontal during the late time window than during the early time window, $F(3.20, 108.79) = 32.86$, $MSE = .03$, $\eta^2 = .49$, $p < .001$. The topography of the old/new effect was also different between the two time windows, $F(4.99, 169.67) = 4.92$, $MSE = .01$, $\eta^2 = .13$, $p < .001$, but follow up comparisons revealed that this was mainly true for the visual study group, $F(3.89, 62.27) = 4.29$, $MSE = .01$, $\eta^2 = .21$, $p < .01$. There was no difference in the scalp distribution of the old/new effect between the early and late time windows for the auditory study group, $F(4.65, 83.72) = 1.45$, $MSE = .01$, $\eta^2 = .07$, $p = .22$.

If rejecting enhanced fluency as evidence of prior study leads to late frontal positivity, then masked repetition priming should be associated with frontal effects for hits as well as CRs following auditory study. This is because participants who receive an auditory study list should be reluctant to interpret enhanced perceptual fluency as evidence of prior study throughout the entire test phase. This was confirmed by the behavioral data reported earlier, which showed that participants who received the auditory study list were actually less likely to claim to recognize test items that were preceded by matching primes. Alternatively, masked repetition priming should lead to late frontal positivity only for CRs following visual study. Figure 3 shows the *ERPs* recorded from channel Fpz for studied and unstudied items that were preceded by matching vs. non-matching primes. As can be seen, priming led to enhanced positivity for CRs in both groups. However, priming also led to enhanced positivity for hits when the study phase was auditory. This was confirmed by the fact that, during the 500–700ms window, masked repetition priming led to enhanced positivity at channel Fpz following auditory study, $F(1, 18) = 7.02$, $MSE = 8.95$, $\eta^2 = .28$, $p = .02$, but not following visual study, $F(1, 16) = 1.04$, $MSE = 6.12$, $\eta^2 = .06$, $p = .32$. More importantly, there was a significant interaction between test item status and prime type in the visual study group, $F(1, 16) = 5.77$, $MSE = 4.10$, $\eta^2 = .27$, $p = .03$, but no such interaction in the auditory study group, $F < 1$.

3. Discussion

The primary goal of the present study was to determine whether masked repetition priming affects *ERPs* differently depending on whether people are biased by encoding conditions to interpret perceptual fluency as evidence of prior study. Based on prior behavioral work (Miller et al., 2008; Westerman et al., 2003), we predicted that participants who received an auditory study list followed by a visual recognition memory test should be reluctant to interpret enhanced perceptual fluency as evidence of prior study. Therefore, for these participants, we predicted that enhanced fluency at test should be associated with a unique neural signature that is characteristic of discounting fluency as a cue for recognition (Wolk et al., 2004). Consistent with our predictions, we found that masked repetition priming led to positive *ERPs* not only during an early 300–500ms time window, which has been reported previously (Misra & Holcomb, 2003; Woollams et al., 2008), but also during a later 500–700ms time window. Most importantly, unlike the earlier effect, the later masked repetition priming effect exhibited a frontal scalp distribution, and it was most pronounced following

auditory study and during test trials associated with correct rejections. Given that this pattern of results is highly consistent with earlier work that examined the neural correlates of discounting conceptual fluency (Wolk et al., 2004) we suggest that late frontal positivity in response to perceptually fluent stimuli reflects an individual's tendency to reject enhanced fluency as evidence of prior study. Furthermore, given the similarity between the present results and the ones reported by Wolk et al., our findings suggest that similar neural mechanisms might be involved in the evaluation and interpretation of perceptual and conceptual fluency.

One finding that was initially surprising was the way in which masked repetition priming differentially affected recognition decisions following auditory and visual study. Unlike in earlier behavioral studies, we found that priming led to a slight decrease in positive recognition responses when the study phase was auditory, and more surprisingly, that it had no effect on positive recognition responses when the study phase was visual. Although this pattern of behavioral results was unanticipated, we do not believe that it undermines the general conclusion that people adopt different interpretations of perceptual fluency following visual and auditory study, and that people generally disregard enhanced perceptual fluency as evidence of prior study when there is a change in sensory modality between study and test (Miller et al., 2008; Westerman et al., 2002). Nonetheless, some explanation of these findings, in particular the lack of a positive priming effect following visual study, is warranted. First, it is unlikely that this pattern of results could have been due to the fact that masked repetition priming was an effective manipulation of fluency for one group and not the other. Participants in both groups received the exact same recognition memory test, and the reaction time data suggest that priming sped up processing of test words to a similar degree in both groups. Alternatively, given that fluency is a potent cue for affective judgments (e.g., Chenier & Winkielman, 2009; Reber, Schwarz, & Winkielman, 2004; Reber, Winkielman, & Schwarz, 1998; Winkielman, Halberstadt, Fazendeiro, & Catty, 2006), perhaps the use of liking judgments at encoding biased participants to interpret enhanced fluency as evidence of liking rather than recognition during the test phase. Although we cannot rule out this possibility, we think it is unlikely given that Woollams et al. (2008) also required participants to make liking judgments at encoding and nonetheless observed standard positive priming effects on recognition decisions.³

We believe that the most plausible explanation for why priming failed to affect recognition decisions following visual study is that the anticipated priming effect was obscured by elevated responding to items preceded by non-matching primes. Positive recognition responses to items preceded by non-matching primes might have been elevated relative to true baseline responding because all non-matching prime words were actually other items from the test. In fact, 50% of items from non-matching prime trials appeared on the test as a non-matching prime word *before* they appeared on the test as an actual test item. Therefore, on a given test trial one could have seen the word *CAT* as a non-matching prime word, and on a later test trial, the same participant could have been asked to make a recognition

³Another possibility is that participants did not rely on fluency during the recognition test because they were consciously aware of the presence of the prime words. Given the long test list, it is likely that some participants were consciously aware of the primes. Indeed, after completing the experiment some participants volunteered that they found that test difficult because they kept getting "messed up by the flashing words" and by the fact that some words "appeared twice on the test." Nevertheless, other participants expressed genuine surprise when informed during debriefing about the priming manipulation. Although Jacoby and Whitehouse (1989) originally proposed that priming has less of an effect on recognition decisions when participants are consciously aware of the prime words (because participants are able to correctly attribute enhanced fluency to the presence of the prime rather than to prior study), this interpretation has recently been called into question by a set of experiments by Huber, Clark, Curran, and Winkielman (2008). This set of studies provides compelling evidence that the repetition priming effect on recognition decisions is more strongly influenced by prime word duration than by conscious awareness of primes. In light of this, the prime duration that we used is well within the boundaries identified by Huber et al. for elevating positive recognition responses via masked repetition priming.

decision about the word *CAT*. We chose to adopt this method because we wanted our paradigm to be as similar as possible to the one employed by Woollams et al. (2008).

To investigate whether the priming effect was blunted by elevated positive recognition responses on non-matching prime trials, we reanalyzed the behavioral data from non-matching prime trials and compared responses on trials where the item appeared first as a prime word with trials where the item appeared first as a test word. This revealed that there was a significant item status (studied vs. unstudied) $\times$ trial type (item appeared on the test first as a prime vs. first as a test word) $\times$ group (visual study vs. auditory study) interaction, $F(1, 37) = 4.39$, $MSE = .002$, $\eta^2 = .11$, $p = .04$. Although responses did not differ between the two types of non-matching prime trials following auditory study (.51 when the item appeared first as a prime word vs. .50 when the item appeared first as a test word), following visual study participants were more likely to claim to recognize studied items that appeared on the test first as a non-matching prime word ($M = .74$) compared to those that appeared on the test first as a test word ($M = .70$), $t(19) = 3.15$, $SE = .01$, $p < .01$. There was no difference in responses to unstudied items that appeared on the test first as a non-matching prime word ($M = .23$) compared to those that appeared on the test first as a test word ($M = .26$), $t(18) = 1.79$, $SE = .02$, $p = .09$. Moreover, when we compared responses on matching prime trials with responses on non-matching prime trials where the item appeared first as a test word (assuming this subset of trials provides the best estimate of baseline responding), we found that, following visual study, masked repetition priming had a differential effect on hits and false alarms, such that priming elevated hits and slightly reduced false alarms [item status $\times$ prime type interaction, $F(1, 19) = 7.61$, $MSE = .002$, $\eta^2 = .27$, $p = .01$]. Following auditory study, however, priming led to a marginally significant reduction in both hits and false alarms, [main effect of prime type, $F(1, 18) = 3.68$, $MSE = .004$, $\eta^2 = .17$, $p = .07$]. Why priming selectively elevated hits following visual study is unclear (especially given that fluency usually has a larger effect on false alarms; cf. Kurilla & Westerman, 2008), but we point out that this is consistent with the analysis of the reaction time data, which showed that priming led to a larger reduction in RTs for studied words than for unstudied words. This suggests that priming might have been a more potent manipulation of fluency for studied than unstudied items. So, although we cannot rule out the possibility that priming might have affected retrieval success in addition to perceptual fluency, we regard this finding as important because it suggests that participants in the visual study group may have relied on fluency to make at least some portion of their recognition decisions. Furthermore, as shown in Figure 3, masked repetition priming led to frontal positivity during the 500–700ms window in every instance *except* hits following visual study. That the late frontal priming effect manifests in every instance except the one condition in which participants might have interpreted fluency as evidence of prior study bolsters our conclusion that this *ERP* effect reflects participants' active discounting of fluency, rather than their general reliance on fluency to make any type of decision.

Although we interpret the late frontal priming effect as reflecting an individual's tendency to discount fluency as evidence of prior study, it is important to note that the frontal *ERP* effect observed in the current study peaked at a much earlier point in time than that which was reported by Wolk et al. (2004). In the present study, enhanced positivity to perceptually fluent test items occurred between 500 and 700ms, whereas in the study conducted by Wolk et al., enhanced positivity to conceptually fluent test items occurred between 1200 and 1600ms. Although there are many differences between the two studies that could potentially explain this (e.g., participants made speeded recognition decisions in the present study, whereas participants in the study conducted by Wolk et al. were required to wait 1500ms following stimulus presentation to make their response) one possibility is that this difference in onset latency is related to the relative weight that people attach to different types of fluency during a recognition task. Numerous findings suggest that conceptual implicit

memory is functionally similar to episodic familiarity. For instance, familiarity and conceptual implicit memory are similarly affected by a number of experimental manipulations (e.g., Challis & Sidhu, 1993; Hamann, 1990; Mulligan & Stone, 1999; Srinivas & Roediger, 1990), and neither familiarity nor conceptual implicit memory are impaired in cases of amnesia (e.g., Carlesimo, 1994; Cermak, Verfaellie, & Chase, 1995; Gardner, Boller, Moreines, & Butters, 1973; Graf, Shimamura, & Squire, 1985; Lazzara, et al., 2001; Shimamura & Squire, 1984; Vaidya, Gabrieli, Kean, & Monti, 1995). Therefore, people might regard conceptual fluency as more convincing evidence of prior study than perceptual fluency. As such, it might take people longer to reject enhanced conceptual fluency as a basis for recognition. Elsewhere, others have argued that conceptual fluency probably contributes to recognition memory more so than perceptual fluency, especially in recognition tasks that involve highly meaningful stimuli (Voss & Paller, 2006; Voss & Paller, 2008).

As mentioned in the introduction, familiarity is often thought to be associated with a frontally distributed positivity to studied items at around 300–500ms, whereas recollection is thought to be associated with a more parietally focused positivity to studied items at around 500–700ms. The former is referred to as the *FN400*, and the latter is referred to as the late parietal complex (*LPC*). We did not find clear evidence in the present study of either of these components. Instead, *ERPs* for hits exhibited a central topography during the 300–500ms window, and a central and somewhat anterior, right lateralized topography (especially following visual study) during the 500–700ms window (see Figure 1). Given that our experiment included neither measures of familiarity and recollection, nor manipulations designed to influence these processes, it is difficult to know for sure what the *ERP* effects in these time windows reflect. However, we point out that there has been considerable debate as to whether the *FN400* reflects episodic familiarity or conceptual priming (Voss & Paller, 2006; Voss & Paller, 2008). Those who adopt the latter position contend that the *FN400* is functionally equivalent to the *N400*, which reflects semantic processing and typically exhibits a central scalp distribution (Kutas & Hillyard, 1980). Although the *FN400* exhibits a frontal topography (indeed, this is its characteristic feature), it has been suggested that this could be due to the presence of overlapping components, such as the *LPC*, during a recognition task (Voss & Federmeier, 2011). If requiring participants to make speeded recognition decisions in the present study disrupted conscious recollection and attenuated the magnitude of the *LPC*, then this could explain why a clear *FN400* was not observed in the present study. Furthermore, given that recollection should be weak or absent in the present experiment, *ERPs* during the 500–700ms period might simply reflect other processes, including continuation of processes from the preceding time window or the beginning of engagement of later processes, both of which may normally be obscured by a robust *LPC*.

Finally, it is important to point out that the masked repetition priming effect on *ERPs* during the 300–500ms time window was independent of the magnitude of the priming effect on recognition decisions. This suggests that the positivity observed in the early time window might reflect an individual's experience of fluency rather than their actual use of fluency to make a recognition decision. As a considerable body of work has shown, people do not automatically interpret enhanced fluency as evidence of prior study (Kleider et al., 2004; Miller et al., 2008; Westerman et al., 2002, 2003; Westerman, 2008; Whittlesea et al., 1990). What is critically important in determining whether fluency affects recognition decisions is whether people adopt a cognitive interpretation of fluency as evidence of prior study. The present findings suggest that the neural correlates of adopting an interpretation of fluency (i.e., interpreting fluency as evidence of something other than prior study) occur relatively late in time. Whether this means that strategic control of the fluency heuristic is guided by conscious processing is difficult to say, especially given that fluency is not a cognitive

operation, per se, but rather a feeling of ease associated with cognitive processing. As such, a feeling of fluency can be generated by almost any type of cognitive or motor operation (Oppenheimer, 2008), and different types of fluency might be subject to greater or lesser degrees of conscious, strategic control. Nonetheless, the present findings are important because they demonstrate that late, frontal positive *ERPs* in response to fluent test stimuli index not only the discounting of conceptual fluency (Wolk et al., 2004), but also the discounting of perceptual fluency as a cue for recognition. Presumably, this could serve as a useful tool for investigating issues such as the conditions that either promote or discourage use of the fluency heuristic during recognition memory tasks, and lead to a greater understanding of how and when fluency influences recognition decisions.

4. Method

4.1 Participants

Forty volunteers (26 female; ages 18–28 years old) from the University of Illinois at Urbana-Champaign participated in the current study. Half the participants were randomly assigned to the visual study group, and half were assigned to the auditory study group. All participants were right handed and reported to be in good health and with normal or corrected-to-normal vision. All participants were tested individually in a sound attenuating booth and received monetary compensation.

4.2 Materials

The stimuli consisted of 406 words taken from Gonsalves and Paller (2000). The words were four to eight letters in length and possessed an average Kucera-Francis written frequency of 31.69 occurrences per million. Two-hundred six words appeared on the study list and 400 appeared on the test list, which was comprised of an equal number of studied and unstudied words. The six words occupying the first and last three serial positions of the study list were used as primacy and recency buffers, and they did not appear on the test. All other stimuli were randomly presented and counterbalanced across participants so that each item was equally likely to appear as a studied or unstudied word and equally likely to be preceded by a matching or non-matching prime.

Stimuli were presented visually in the center of a computer monitor or aurally over loudspeakers. Participants were seated approximately 60 cm from the computer monitor with their right hand positioned over a response box. Stimulus presentation and response collection were controlled by E-Prime (Psychology Software Tools, Pittsburg, PA; www.pstnet.com).

4.3 Experimental Procedure

Participants were randomly assigned to either the visual study group or the auditory study group. A short practice session was administered prior to the actual experiment to familiarize participants with the task. Afterwards, participants were given the opportunity to ask questions. Once all their questions were answered, they proceeded to the actual experiment.

Participants in both groups studied a list of 200 words. Each study trial began with a fixation cue (>#####<) presented for 500ms. In the visual study group, this was followed by a visual presentation of a word for 300ms, followed by a blank screen for 1700ms. In the auditory study group, the fixation cue was followed by an auditory presentation of a word for 2s. Participants in both groups were instructed to decide whether each word was relatively interesting by pressing a button on the response box. Participants were told to press the button labeled “5” for words they liked and to press the button labeled “6” for words they

did not like. This task was intended to prevent participants from using their own mnemonic strategy during encoding, and liking judgments were not actually recorded.

Each test trial was self-paced and began with the message, “Press 4 for next trial.” Following a 200ms interval, a forward mask (>#####<) was presented on the screen for 500ms. This was followed by presentation of a prime for 43ms and a backward mask for 500ms. On half the test trials the prime was the same as the subsequent test word (matching primes), and on half the test trials the prime was different from the subsequent test word (non-matching primes). Non-matching primes were always the same study status as the subsequent test item. Thus, test items preceded by non-matching primes were paired with another word that occurred in the test (see Woollams et al., 2008). Participants were not informed about the occurrence of the primes, but they were informed about the occurrence of the number signs before each test item. Participants were instructed to use these number signs as a signal that the test word is about to appear. Test words remained on the screen for 300ms. Following offset of the test item, participants were asked to make a response. They were instructed to press 5 for test items that were studied and to press 6 for test items that were not studied. After they made a response, the next trial began. Participants were instructed to make their recognition decision as quickly and as accurately as possible. If they failed to make a response within 2s, feedback was provided indicating that they were too slow to respond, and the next trial began. Trials on which participants failed to respond during the allotted time were discarded.

4.4 EEG recording, data processing, and ERP analysis

The electroencephalogram (EEG) was recorded using the ActiveTwo active electrode system from Bio-Semi (www.Biosemi.com). Sixty-four Ag/AgCl electrodes were positioned in a nylon cap according to an extension of the international 10–20 system (Chatrian et al., 1988). Six additional electrodes were positioned on the mastoids, to the outside of each eye, and under each eye. The *EEG* and electrooculogram (*EOG*) were continuously recorded using a reference-free procedure, amplified with a bandpass of 0.16 to 100Hz, and sampled at a rate of 512Hz. The data were re-referenced offline to the average of the left and right mastoid recordings and band-pass filtered at 0.10–50Hz. Epochs were created by taking 200ms prior to the onset of each test stimulus to 1000ms after, and baseline corrected to the 200ms pre-stimulus interval. Epochs containing extreme artifacts (changes of more than 100μV from baseline) were discarded. *ERPs* were generated by averaging together the epochs for each condition of interest time-locked to the onset of the test stimulus. All conditions included in statistical analyses were required to have a minimum of 20 artifact free trials per participant; participants with fewer than 20 artifact free trials in any condition of interest were excluded from analyses.

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Highlights

- We examined neural activity due to attribution of perceptual fluency in recognition.
- We manipulated fluency attribution by varying the sensory modality of the study list.
- Repetition priming decreased positive recognition responses after auditory study.
- Priming also led to late, frontal positive *ERPs* following auditory study.
- Late frontal positivity might reflect discounting of fluency during recognition.

Figure 1. Top: ERPs for hits and correct rejections for the visual study group (left) and the auditory study group (right). Bottom: Topographic maps depicting the old/new effect.

Figure 2.

Top: *ERPs* for matching and non-matching prime trials at Cz, plotted separately for hits (top) and for correct rejections (bottom), and for the visual study group (left) and the auditory study group (right). Bottom: Topographic maps depicting the masked repetition priming effect between 300–500ms.

Figure 3. Top: ERPs for matching and non-matched prime trials at Fpz, plotted separately for hits (top) and correct rejections (bottom), and for the visual study group (left) and the auditory study group (right). Bottom: Topographic maps depicting the masked repetition priming effect between 500–700ms.

Table 1

Signal detection estimates of discrimination and criterion placement

<u>Group/estimate</u>	<u>Prime type</u>	
	Non-Matching	Matching
<i>Visual Study</i>		
<i>d'</i>	1.48 (.18)	1.41 (.16)
<i>C</i>	.08 (.11)	.05 (.10)
<i>Auditory Study</i>		
<i>d'</i>	1.49 (.19)	1.46 (.17)
<i>C</i>	.13 (.10)	.02 (.10)

Note: Standard error of the mean (*SEM*) in parentheses.

Table 2

Hits and false alarms from each condition.

<u>Group/item status</u>	<u>Prime type</u>	
	Matching	Non-Matching
<i>Visual Study</i>		
Studied	.73	.72
Unstudied	.24	.25
<i>Auditory Study</i>		
Studied	.71	.74
Unstudied	.23	.27

Note: SEM ranged from .03 to .05. One participant in the auditory study group was excluded because they exhibited a priming effect that was 2.6 *sd* above the mean for that group.

Table 3

Mean of median reaction times from each condition.

<u>Group/item status</u>	<u>Prime type</u>	
	Matching	Non-Matching
<i>Visual Study</i>		
Studied	673.53	888.80
Unstudied	912.75	973.23
<i>Auditory Study</i>		
Studied	613.03	812.45
Unstudied	821.06	921.50

Note: SEM ranged from 34.47 to 56.78. One participant in the auditory study group was excluded because they exhibited a priming effect that was 2.6 *sd* above the mean for that group.