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An electrophysiological investigation of the relationship between conceptual fluency and familiarity

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Abstract

Brain potentials associated with the manipulation of conceptual fluency in a recognition memory paradigm were recorded. Enhanced fluency was associated with attenuation of the N400 and an increased rate of subjects' endorsing both studied and non-studied items as having been studied ("old" responses) in the recognition test. Differences were also found in latencies previously associated with post-retrieval processing, such that in the setting of enhanced fluency (1) non-studied items were associated with a positive wave from 800 to 1600 ms and (2) items endorsed as "new" were more positive than those endorsed as "old" from 1200 to 1600 ms. The effects on the N400 may be related to the impact of fluency on familiarity, whereas later processing may be involved in the attribution of fluency to prior experience.

Keywords: Event-related potential; Familiarity; Conceptual fluency; Memory; N400; Semantics

Dual-process accounts of recognition memory posit that *familiarity* and *recollection* are two distinct memory processes underlying recognition memory (for review see [27]). Recollection is often described as the detailed retrieval of information regarding an item or event, including the context in which it was experienced, while familiarity is thought to represent a vague sense of prior encounter. Event-related potential (ERP) studies of recognition memory support such accounts and have demonstrated distinct correlates of familiarity (300–550 ms) and recollection (500–800 ms). The familiarity correlate is similar to the N400 component [3,7,16,19], which in studies of language has been shown to be modulated by the ease with which an item is semantically integrated into its context [10], but is often more anteriorly distributed. ERP studies of memory have also demonstrated a correlate thought to reflect activity in the prefrontal cortex involved with the evaluation of the contents of memory (often referred to as *post-retrieval processing*), which appears later (800–1600 ms) and is frontally based [9,16,18,26].

There is increasing evidence that the ease with which an item is processed, also referred to as its *fluency*, provides an important basis for familiarity [13,23]. The finding that prior presentation of an item leads to easier identification when that item is re-presented in a degraded fashion [11] led Jacoby and others to speculate that enhanced processing fluency could be used as a cue that an item was previously studied when making recognition judgments [11–13,23,24]. Consistent with this notion, initial work demonstrated that manipulations of *perceptual fluency*, such as varying the visual clarity of test items, result in an increased likelihood that the more fluent (or easier to perceive) items will be endorsed as having been studied [12,24]. Methods to estimate the relative impact of such manipulations on familiarity and

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recollection support the relationship of fluency to familiarity, but not recollection [14,17].

Further work has suggested that *conceptual fluency* (the ease of conceptual processing) can also influence recognition memory judgments [23,25]. Test words preceded by a conceptually predictive context are more likely to be endorsed as previously studied than items preceded by a non-predictive context [23,25]. For example, subjects are more likely to say that the word "boat" was on a study list if it follows the predictive sentence stem, "The stormy seas tossed the . . ." than the non-predictive stem, "She saved up her money and bought a . . ." Words following predictive stems are thought to be more easily processed (more conceptually fluent) than those following non-predictive stems (akin to conceptual priming), and this enhanced fluency may then be mistaken for prior study.

However, it has been theorized that enhanced fluency does not result in an increase in familiarity unless this enhanced fluency is attributed to prior experience, and not to an alternative source [12,24,25]. Several studies have shown a diminution of fluency effects on recognition due to participants' awareness that the source of enhanced fluency is due to the experimental manipulation itself rather than prior study [12,24].

We sought to evaluate the electrophysiological correlates of conceptual fluency in recognition memory by preceding words for recognition judgment with predictive or non-predictive sentence stems. Because fluency has been proposed to preferentially impact familiarity, we expected enhanced fluency to produce an attenuated, or a less negative, N400-like effect, as has been associated with increased familiarity [3,7,16,19]. We also hypothesized that attribution decisions related to enhanced fluency, which are critical to recognition judgments as evidenced from behavioral studies, may be a type of post-retrieval processing. Thus, we expected that items following predictive stems (with enhanced fluency) would demonstrate modulations in a temporal latency (800–1600 ms) and spatial distribution (frontal) characteristic of such processing.

Informed consent was obtained in 16 healthy right-handed students at Harvard University (seven males; mean age: 19 years; range: 18–21 years). The study was approved by the human subjects committee of Brigham and Women's Hospital, Boston, MA. One participant was excluded due to excessive ERP artifact.

The stimuli were adapted and expanded from Whittlesea and Williams [25]. Each of 240 one-syllable words was matched with a pair of sentence stems, one that predicted the word and the other that was merely consistent with it (non-predictive).

In a self-paced study session, participants counted the number of "e"s in 120 visually presented, upper-case words. At test, 120 studied and 120 non-studied words were presented in a pseudo-random order in both the visual (lower case) and auditory modalities for recognition judgment. Sixty studied and 60 non-studied words were preceded by a predictive sentence stem; the other 60 studied and 60 non-studied words were preceded by a non-predictive stem. Stems were also presented in the visual and auditory modalities. Auditory stimuli were pre-recorded and had an onset simultaneous with visual presentation (we felt auditory presentation would further ensure attention to the sentence stems). Four study-test lists were counterbalanced by study and stem type. Stem presentation time varied based on the auditory presentation. Next, was a 250 ms pause, then the final word (for 1000 ms), followed by a 500-ms interval prior to an "Old or New?" prompt. Subjects were told to refrain from responding until this prompt appeared. The subject's response was entered by the experimenter. A "+" sign appeared for 1000 ms marking the start of the next trial.

A stem type (predictive, non-predictive) × item type (studied, non-studied) ANOVA revealed an effect of item type [$F(1,14) = 75.27$, $P < 0.00001$] with studied items being called "old" more often than non-studied items (0.56 versus 0.41) and, replicating prior studies, an effect of stem type [$F(1,14) = 22.8$, $P < 0.001$] with items following predictive stems more often called "old" than items following non-predictive stems (0.53 versus 0.44). There was no interaction [$F(1,14) < 0.1$].

ERPs were recorded at test from 29 scalp sites referenced to the left mastoid: 7 midline (FPz, Fz, FCz, Cz, CPz, Pz, Oz) and 22 lateral (FP1/2, F3/4, FC3/4, C3/4, CP3/4, P3/4, O1/2, AF7/8, F7/8, FT7/8, T7/8). Electrodes were placed below the left eye (LE) and lateral canthi of both eyes (HE) to monitor for blinks and horizontal eye movements. The ERPs were amplified (0–40 Hz), and the recorded data were digitized (100 Hz) beginning 100 ms before onset of the test word. Trials were analyzed for 1600 ms following stimulus presentation. Trials with amplifier blocking or eye movements were excluded; blinks were corrected [5] for subjects with excessive trials contaminated by blinks. Only ERPs formed from 16 or more artifact free trials were accepted for analysis [26].

Three chains of electrode sites (left, midline, right) were analyzed to cover a relatively broad spatial range of neural activity. The Greenhouse–Geisser procedure was used for all ANOVAs with greater than one numerator degree of freedom. For brevity, main effects of electrode and non-significant results will not be reported unless relevant. For the first analysis, ERPs were calculated for predictive–studied, non-predictive–studied, predictive–non-studied, and non-predictive–non-studied items. Two latencies were examined: 300–550 ms for evaluation of the N400 and 800–1600 ms for correlates of post-retrieval processing. Mean ERP amplitude relative to a 100-ms prestimulus baseline was calculated for the intervals. It should be noted that we did not find a clear recollection ERP correlate (500–800 ms), which is likely due to the difficulty of the memory task resulting in poor discrimination and a greater reliance on familiarity.

In the 300–550 ms latency, a stem type (predictive, non-predictive) × item type (studied, non-studied) × electrode (FP1/z/2, F3/z/4, C3/z/4, P3/z/4, O1/z/2) × chain (left, middle, right) ANOVA was performed. This analysis revealed an

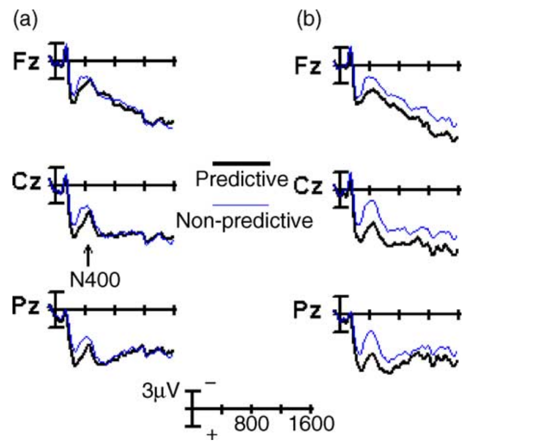

Fig. 1. Grand average ERP plots for three midline sites. ERPs of (a) studied and (b) non-studied items following predictive and non-predictive sentence stems.

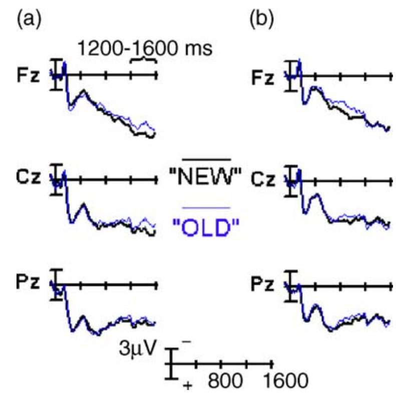

Fig. 2. Grand average ERP plots for three midline sites. ERPs based on participant response for items following (a) predictive and (b) non-predictive stems.

effect of stem type [$F(1,14) = 36.09$, $P < 0.0001$], with items following predictive stems being less negative than those following non-predictive ones, and a stem type × item type interaction [$F(1,14) = 6.78$, $P = 0.021$], which was attributable to the effect of stem type being greater for non-studied than studied items. However, the stem type effect was reliable for both studied [$F(1,14) = 5.33$, $P < 0.037$] and non-studied items [$F(1,14) = 27.37$, $P < 0.001$] (Fig. 1a and b and Fig. 3). A stem type × electrode interaction [$F(4,20.3) = 4.11$, $P = 0.043$] appeared to be attributable to a larger effect of stem type at centroparietal sites. A post hoc comparison of frontal electrodes (FP1/z/2, F3/z/4) with centroparietal electrodes (C3/z/4, P3/z/4) revealed a stem type × region (frontal, centroparietal) interaction [$F(1,14) = 10.68$, $P = 0.006$] confirming this impression. There was also an item type × electrode interaction [$F(4,27.8) = 4.22$, $P = 0.025$] because studied items tended to be less negative than non-studied items at posterior sites (more attenuated N400) while the reverse was true at anterior sites.

An analogous ANOVA was performed for the 800–1600 ms latency which revealed a trend toward an effect of stem type [$F(1,14) = 3.68$, $P = 0.076$], with greater positivity for items following predictive versus non-predictive stems, and a significant stem type × item type interaction [$F(1,14) = 6.93$, $P = 0.020$] attributable to a significant effect of stem type for non-studied items [$F(1,14) = 9.58$, $P = 0.008$], but not for studied items (Fig. 1a and b).

In order to evaluate the electrophysiological correlates of response in the context of the manipulation of fluency, "old" and "new" responses were collapsed for studied and non-studied items (to provide an adequate number of artifact free trials for each subject [26]). Thus, ERPs were calculated for predictive–"old", predictive–"new", non-predictive–"old", and non-predictive–"new" items. A stem type (predictive, non-predictive) × response ("old", "new") × electrode (FPz/1/2, Fz/3/4, Cz/3/4, Pz/3/4, Oz/1/2) × chain (right, left, midline) ANOVA was performed for three latencies: 300–550 ms, 800–1200 ms, and 1200–1600 ms. Evaluation of post-retrieval processing activity was divided into two intervals (800–1200 ms and 1200–1600 ms) in order to best capture differences between response and stem type noted on inspection of the waves. Effects and interactions commented upon previously will not be repeated.

In the 300–550 ms latency there was no effect of response [$F(1,14) < 1$] and no interactions. In the 800–1200 ms latency, there was a main effect of stem type [$F(1,14) = 5.98$, $P = 0.028$] and a marginally significant effect of response [$F(1,14) = 4.49$, $P = 0.053$], with items called "new" having a more positive voltage than items called "old". There were no interactions with response, including stem type × response [$F(1,14) < 1$].

In the 1200–1600 ms latency there were no main effects of stem type or response. However, there was a marginal stem type × response interaction [$F(1,14) = 4.38$, $P = 0.055$], such that "new" responses were more positive than "old" responses following predictive stems [$F(1,14) = 5.48$, $P = 0.035$] (Fig. 2a and Fig. 4a), but not following non-predictive stems [$F(1,14) < 1$] (Fig. 2b and Fig. 4b). Because of previous findings linking prefrontal activity with post-retrieval processes [9,16,18,26], planned comparisons between "old" and "new" responses following the predictive stem were conducted for the six frontal and six posterior sites separately. Response ("old", "new") × electrode (FPz/1/2, Fz/3/4 or Pz/3/4, Oz/1/2) × chain (left, midline, right) ANOVAs

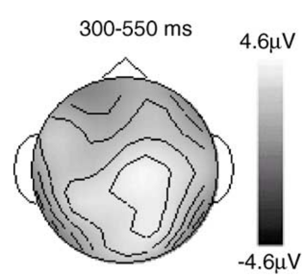

Fig. 3. Topographic distribution of ERP differences between non-studied items following predictive stems minus non-studied items following non-predictive stems at 300–550 ms.

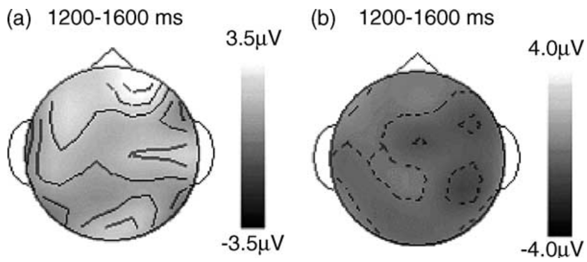

Fig. 4. Topographic distributions of ERP differences between "new" responses minus "old" responses at 1200–1600 ms following (a) predictive stems and (b) non-predictive stems.

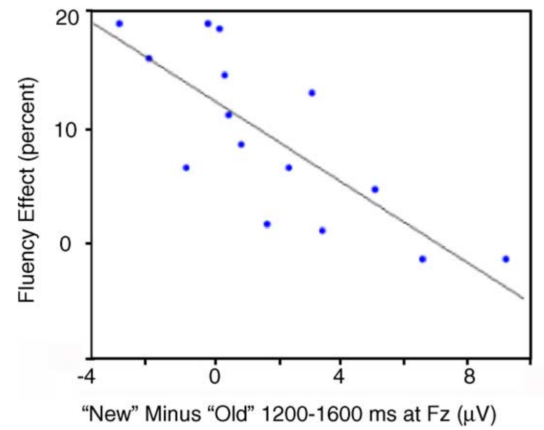

Fig. 5. Correlation between mean ERP amplitude (1200–1600 ms) at Fz of "new" minus "old" responses following predictive stems with effect of fluency on recognition performance (percent "old" responses following predictive stems minus percent "old" responses following non-predictive stems).

were performed. This revealed a main effect of response for frontal sites [$F(1,14) = 8.19$, $P = 0.013$], but not posterior sites [$F(1,14) = 2.27$, $P = 0.15$]. It should be pointed out that correlates of post-retrieval processing are often, but not always [9,18], reported to be more prominent in the right hemisphere. Although this was not statistically the case, inspection of the topographic map (Fig. 4a) reveals the effect to be most prominent over the right prefrontal cortex.

To further investigate the nature of this activity, correlations of this effect with recognition performance were examined. Since endorsement of an item as "new" in the setting of a predictive stem can be construed as rejection of enhanced fluency as indicating prior study, we hypothesized that the positive voltage associated with "new" responses relative to "old" responses was reflective of such processing. As a result, we predicted that those subjects who demonstrated an overall smaller effect of fluency in their recognition judgments (those who, to a greater extent, rejected enhanced fluency as a cue of prior study) would demonstrate greater positivity of "new" versus "old" responses.

Mean ERP amplitude in the 1200–1600 ms latency for "new" minus "old" responses of items following predictive stems was calculated at frontal sites (FPz/1/2, Fz/3/4) for each subject. Fluency effect was defined as percent of items (studied and non-studied) endorsed as "old" following predictive stems minus the percent endorsed as "old" following non-predictive stems. A Pearson correlation revealed a significant negative correlation at the Fz and F4 electrode sites (Fz: $r = -0.78$, $P < 0.001$, F4: $r = -0.53$, $P = 0.043$). No other frontal sites had statistically significant correlations (Fig. 5).

Manipulations of fluency were associated with modulations of the N400 and later, frontally maximal components. We will address these effects in succession.

As predicted, enhanced fluency was associated with an attenuated (less negative) N400. It should be noted that the effect of fluency on the N400 was smaller for studied than non-studied items. This finding is likely related to studied items generating their own enhanced fluency as a result of prior study. The fluency generated from prior study may then have produced a "ceiling effect" on the degree of attenuation possible, resulting in the absolute impact on the N400 to be smaller than for non-studied items. As attenuation of an N400-like component has been previously associated with familiarity [3,7,16,19], this result may be interpreted as consistent with the link between fluency and familiarity, as advanced in behavioral studies [14,17].

However, in contrast to the maximal centroparietal topography of the N400 effect in the present study, many recognition memory studies have found a more frontocentrally based attenuation correlated with familiarity [3,16,19]. Indeed, some researchers have suggested that the N400 old/new repetition effect is composed of two distinct sources, a frontal one related to familiarity and a centroparietal source involved in implicit memory [4,19]. As data from behavioral studies argues that enhanced fluency increases familiarity, the relationship of the more posterior N400 attenuation with enhanced conceptual fluency in the present study suggests that more posterior neural generators may also contribute to the conscious feeling of familiarity. Although this remains speculative, there is some support in the literature for the relevance of these more posterior generators [7,8]. For example, Duzel et al. reported a temperoparietal attenuation in the N400 range associated with the subjective experience of "knowing", a state thought to reflect familiarity. In addition, a recent report by Finnigan and colleagues demonstrated a reliable, strength-based attenuation of the centroparietal N400, which was not found at more frontal sites. These authors argue that their concept of strength is commensurate with that of familiarity as argued by Curran and colleagues and others [2,27]. Further, they found that this posterior attenuation was greater for hits than misses. Importantly, it was the lack of such a difference that led Rugg et al. [19] to conclude that this posterior modulation reflects implicit memory. Nonetheless, it is worth noting that the effect of fluency in the present study encompassed a broad area, extending into frontal sites (see Figs. 1 and 3); accordingly, the necessity of more anterior neural generators in the experience of familiarity merits further investigation.

Indeed, several recent reports have demonstrated inconsistencies of the mid-frontal N400 with properties of familiarity

[2,22,28], suggesting it may be the case that such anterior neural generators do not always underlie familiarity, and, as such, familiarity may not be unitary electrophysiological construct. A recent recognition study by Schloerscheidt and Rugg [20] may be informative in this regard. They manipulated the presentation format of items at study and test, such that some items were within format (i.e. studied as a word or picture and then tested in this same format) while others were across format (i.e. studied as a word and then tested with a corresponding picture or vice versa). They found that early frontal activity (300–600 ms), similar to previously described familiarity correlates [3,16,19], was modulated by the degree of perceptual similarity of items from study to test leading them to argue that this frontal modulation is sensitive to familiarity based on perceptual fluency. However, they speculated that other processes that support familiarity, such as conceptual fluency, may have different correlates. Thus, the more posterior N400 effect in the present study may reflect such conceptually driven familiarity.

Finally, it is important to note that modulation of the N400 associated with the fluency manipulation provides a convergence between research related to linguistic processing and recognition memory. Research concerning language processing supports the notion that the N400 may be directly related to the effort required to integrate a word with its context [10]. However, the degree to which semantic relations are processed can impact their effect on the N400, reducing it when such relations are less relevant to the task [1,6]. In the present study, the semantic relationship of the sentence stems to the final words was irrelevant to whether the word had been previously studied. That stem type still modulated the N400 in this setting suggests that subjects may attempt to integrate an item with its context during recognition judgments. The ease of this integration may then be used as a cue in deciding whether the item was previously encountered. In fact, a study using masked repetition priming by Schnyer et al. [21] suggests that context does not have to be consciously available to impact the N400 in recognition judgments. This finding and that of Misra and Holcomb [15] led the latter authors to argue that the N400 may reflect a controlled process whereby a stimulus is integrated into its context, but that the context does not have to be consciously perceived. This process of semantic integration may be a compulsory aspect of recognition memory when using meaningful stimuli, thereby allowing conceptual fluency to be useful as a cue.

Although attenuation of the N400 (as a result of enhanced fluency) may relate to familiarity, there is considerable behavioral evidence that fluency, per se, is not the sole determinant of whether an item is felt to be previously encountered, but that attribution of enhanced fluency to prior experience is necessary [12,13,25]. Some have argued that such later processing is necessary for the conscious feeling of familiarity to arise [25]. The ERP results of the present study provide electrophysiological support for this notion. Despite the finding that enhanced fluency was associated with an attenuated N400 and a greater likelihood to endorse an item as "old", the N400 was not sensitive to how the participant responded within either condition of fluency (predictive and non-predictive; see Fig. 2). That is, attenuation of the N400 was associated with a greater tendency to endorse an item as previously seen, but was not diagnostic of the participants' response. Although the latter finding endorses the null hypothesis and could be related to the sensitivity of the current study, we believe that it is more likely that later, post-retrieval processes involved in attributions of fluency determine response.

Two results in the present study support the importance of this later processing. First, in the setting of enhanced fluency, non-studied items, with no "memory" effects from prior presentation, demonstrated a prolonged positive wave from 800 to 1600 ms, well beyond the typical duration of the N400 (see Fig. 1b). This positive wave may represent processing involved in the assessment and attribution of enhanced fluency. Second, "new" responses were associated with greater frontal positivity than "old" responses in the setting of enhanced fluency within the 1200–1600 ms latency (see Fig. 4a). Importantly, this later activity was not seen in the less fluent condition (see Fig. 4b), and, thus, may reflect processing involved in the final decision of whether enhanced fluency should be attributed to past experience versus an alternative source.

One speculation is that the positivity from 1200 to 1600 ms associated with "new" responses (whether correct or not), in the setting of enhanced fluency, reflects the effort required to inhibit a fluency-based endorsement bias of the item as previously experienced. In other words, it may be that without additional reflection enhanced fluency is considered related to prior study, and that the later positivity we observed is involved in rejecting this "default" mode. Consistent with this notion is the fact that those subjects who showed less of an effect of fluency on their recognition judgments showed more positive voltages at frontal (Fz, F4) sites for "new" relative to "old" responses. This result suggests that at least some of the neural generators of the late, frontal activity may be associated with the extent to which subjects generally reject the "default" of attributing fluency to prior experience.

The activity we found in later epochs associated with enhanced fluency and subjects' responses appear to have temporal and spatial characteristics consistent with the engagement of post-retrieval processes described in a variety of different memory paradigms. This processing has been associated with evaluation of the products of retrieval for information about source [26], or other item specific features [9,16], and the instantiation of strategic processing related to the required task [18]. The present study adds attributions of fluency to the class of processes likely supported by these post-retrieval activities.

In conclusion, our results demonstrate a centroparietal attenuation of the N400 associated with enhanced conceptual fluency which may correlate with the increased familiarity produced by such a manipulation. The finding that fluency, as represented by this attenuation, is not solely determinant of the participants' response is consistent with prior work emphasizing the importance of attributions of fluency. Our data suggest that this attributional process is a type of post-retrieval processing.

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