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ERP correlates of Remember/Know decisions: Association with the late posterior negativity

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Abstract

A number of studies have utilized the Remember/Know paradigm to determine event-related potential (ERP) correlates of recollection and familiarity. However, no prior work has been specifically directed at examining the processing involved in making the Remember/Know distinction. The following study employed a two-step recognition memory test in which participants first decided whether they recognized a word from a prior study list (Old/New decision); if they did, they then determined whether it was recognized on the basis of recollection ('Remember' responses) or familiarity ('Know' responses). By time-locking ERPs to the initial Old/New decision, processing related to making the introspective Remember/Know judgment was isolated. This methodology revealed a posterior negativity that was largest for 'Remember' responses. Previous work has described a late posterior negativity which appears to be related to the search for and recapitulation of study details. Such processing may be critical in making Remember/Know determinations.

Keywords: Memory; Event-related potentials; Remember-Know

1. Introduction

Dual process models of recognition memory posit that recollection and familiarity are subjective memorial experiences that are related to separate underlying neural processes (Yonelinas, 2002). Recollection supports detailed retrieval of a study episode while familiarity is a sense of prior exposure lacking contextual details. A variety of different techniques have been used to experimentally dissociate these two forms of memory (Jacoby, 1991; Yonelinas, 1994; Gardiner, 1988; see Yonelinas (2002) for review). The validity of these approaches is supported by the largely convergent results they produce (Yonelinas et al., 1998).

The 'Remember/Know' paradigm (Tulving, 1985; Gardiner, 1988) is a commonly used methodology to operationalize these memory processes. In this paradigm subjects are instructed to give 'Remember' responses for recognized items associated with retrieval of contextual information (recollection) and give 'Know' responses when such details are lacking (familiarity). This methodology has been utilized in a number of event-related potential (ERP) studies of recognition memory (Curran, 2004; Duarte et al., 2004; Duzel et al., 1997; Rugg et al., 1998a; Trott et al., 1999). Consistent with the notion that these two forms of memory are subserved by different neural processes, ERP correlates of both recollection [the parietal effect, also referred to as the late positive component (LPC)] and familiarity [the early frontal effect, also referred to as the mid-frontal N400 (FN400)] have been observed using the

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Remember/Know methodology, as well as with other operationalizations (Curran and Cleary, 2003; Rugg et al., 1998b). An additional ERP correlate, the late posterior negativity (LPN), has been reported in recognition memory studies and is postulated to be related to retrieval processes involved in reconstructing and integrating bound study attributes at test (Cycowicz and Friedman, 2003; Friedman et al., 2005; Johansson and Mecklinger, 2003; Li et al., 2004). Given its parieto-occipital location, some have argued that this activity may be specific to the visual modality.

Despite the ubiquitous use of the Remember/Know paradigm in the memory literature, little is known about the neural substrate supporting how subjects assess these memory states. Most ERP studies using this paradigm present items at test for which subjects have to make a 'Remember', 'Know', or 'New' decision. As a result, it is difficult to disentangle processing related to the judgment of whether or not an item is studied (Old/New decision) with the processing involved in assessing the nature of the retrieved information (Remember/Know decision). To better delineate the neural activity associated with each of these decisions, the present study employed a two-step process in which participants first decided whether an item had been previously studied (Old/New); then, for those items thought 'Old', the participant made a Remember/Know decision. By time-locking ERPs to the initial Old/New decision, rather than presentation of the test stimulus, as in the majority of ERP studies, processing involved specifically in making the Remember/Know distinction could be evaluated Fig. 1.

A greater understanding of how one assesses his or her memory, as in making the Remember/Know decision, has a broader importance than just inside the laboratory. Such meta-memory judgments may play an important role in much of our daily behavior. For example, in certain situations, it may be most prudent or effective to only trust memories associated with recollection (e.g., the distinctiveness heuristic; see Budson et al., 2005). Further, whether an item or event is recollected or familiar appears linked to how confident one is that it had been previously encountered (Yonelinas, 1994; Yonelinas et al., 2005). This confidence, which influences how much we trust that memory, may then impact decisions related to it. Although meta-memory

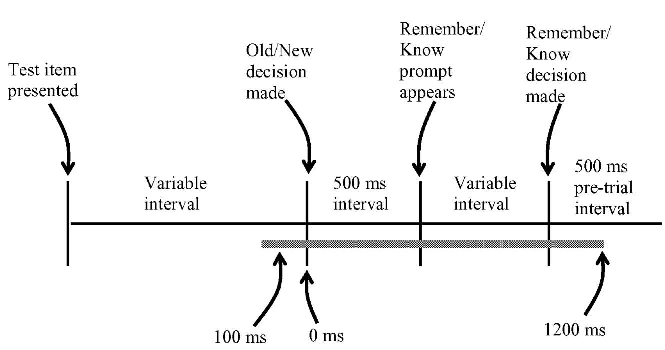

Fig. 1. ERP time interval of interest (represented by gray bar) in the present paper. Traditional ERP analyses time time-lock the interval of interest to start with the presentation of the test item. Here, we time-locked to the participant's Old/New decision to better understand the neural underpinnings of the meta-memorial Remember/Know decision.

is important, the literature on the neural underpinnings of metamemorial assessments is relatively sparse (see Chua et al., 2006, for a recent functional magnetic resonance imaging [fMRI] study addressing confidence assessment).

2. Methods

2.1. Participants

Informed consent was obtained from 31 right-handed undergraduates (18 female; mean age: 20.5 years; range: 18–22 years). Data from four subjects were not included due to inadequate data. Subjects received $25 per hour. The study was approved by the human subjects committees of Brigham and Women's Hospital, Boston, MA and Harvard University, Cambridge, MA.

2.2. Apparatus

ERPs were recorded from 35 active tin electrodes held in place by an electrode cap (Electro-Cap International, Eaton, OH, USA). Electrode locations were based on the International 10–20 system and were arranged in 5 columns, each with 7 antero-posterior sites. The midline sites were FPz, Fz, FCz, Cz, CPz, Pz and Oz. There were two inner lateral columns that included FP1/2, F3/4, FC3/4, C3/4, CP3/4, P3/4, O1/2 and two outer lateral columns that included AF7/8, F7/8, FT7/8, T7/8, TP7/8, P7/8, PO7/8. All sites were referenced to the average mastoid. An electrode was placed below the left eye (LE) for detection of eye blinks and vertical eye movements and the right lateral canthus (referenced to an electrode at the left lateral canthus) to detect horizontal eye movements. The EEG was amplified (0.01–40 Hz, SAI BioAmplifier system), and the recorded data were continuously digitized (200 Hz). Blinks were corrected (Dale, 1994) and trials with amplifier blocking or horizontal eye movements were eliminated. Mean amplitude (relative to a 100 ms baseline before the Old/New response) was calculated from 200 to 800 ms for correctly recognized 'Remember' and 'Know' responses and for correct rejections. This interval was chosen based on examination of the waveforms. Additionally, this interval preceded the Remember or Know response [based on the reaction time data (RT); see below], and, thus, was likely to represent the neural activity involved in making this decision.

2.3. Procedure

Participants studied 300 words (half presented once; half thrice). For each study word, subjects were asked to rate it as 'pleasant' or 'unpleasant' based on their experience. After either a short or long delay (means: 39 min and 23 h, 34 min, respectively), subjects were tested with 600 words (300 studied; 300 non-studied). There were no effects of delay or study repetition in the current analysis, so these conditions were collapsed across all subjects. The analysis of the effect of retention interval on ERP correlates time-locked to test item presentation from this experiment has been previously published (Wolk et al., 2006).

Prior to the test phase, subjects read detailed instructions outlining the Remember/Know distinction, adapted from prior studies using this methodology (Gardiner, 1988; Chua et al., 2006). Each test word was presented after a 500 ms fixation '+'. Test items remained on the computer screen until the subject entered an Old/New judgment (left or right button push). Following this response and a 500 ms inter-stimulus interval, a '?' appeared on the screen. For items endorsed as 'Old', the subject then had to make a 'Remember' or 'Know'

Table 1
Mean proportion of response types

	Studied	Non-studied
'Old'	0.81 (0.11)	0.37 (0.19)
'Remember'	0.50 (0.17)	0.08 (0.09)
'Know'	0.31 (0.11)	0.29 (0.13)

Standard deviation in parentheses.

judgment (top or bottom button push). When the word was thought 'New', subjects were asked to press the same button again to advance to the next item.

3. Results

The behavioral data are presented in Table 1. RTs for 'Remember' and 'Know' responses subsequent to the Old/New decision were 903.8 ms (S.D.: 155.3) and 1098.5 ms (S.D.: 137.0), respectively, which differed significantly [$t(26) = 5.96$, $p < 0.001$].

The ERP data for each of the relevant conditions are presented in Fig. 2. The interval of interest (200–800 ms) was submitted to an analysis of variance (ANOVA) with response type ('Remember', 'Know' and correct rejections) and electrode site (FPz, Fz, Cz, Pz and Oz) as the within-subjects variables. The analysis was restricted to midline sites, as there were no effects of laterality. The Greenhouse–Geisser correction procedure was used for repeated measures factors with greater than one numerator degree of freedom. Only effects of response type or its interactions will be reported.

The initial ANOVA revealed a main effect of response type [$F(2,52) = 15.76$, $p < 0.001$, $\eta^2 = 0.38$] and a response type x site interaction [$F(8,208) = 12.71$, $p < 0.001$, $\eta^2 = 0.33$]. The effect of response type reflects progressively more negative amplitudes from correct rejections to 'Know' to 'Remember' responses (correct rejections > 'Know' > 'Remember'). The interaction with site suggests that this modulation is greatest at posterior sites, as can be clearly seen in Figs. 2 and 3. To follow-up on these effects three response type ('Remember', correct rejections; 'Know', correct rejections; 'Remember', 'Know') x site (Fpz, Fz, Cz, Pz and Oz) ANOVAs were calculated.

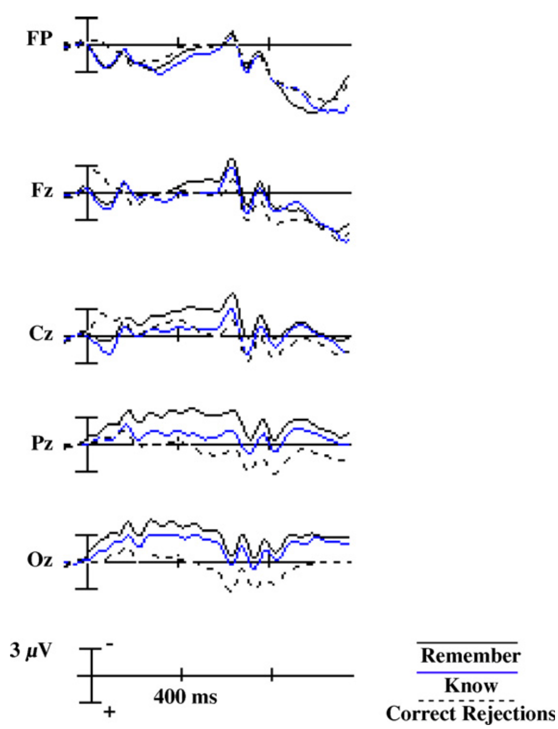

Fig. 2. Grand average ERP plots for 'Remember' responses to hits, 'Know' responses to hits and correct rejections of novel items time-locked to the Old/New decision button press (indicated by the large vertical "I").

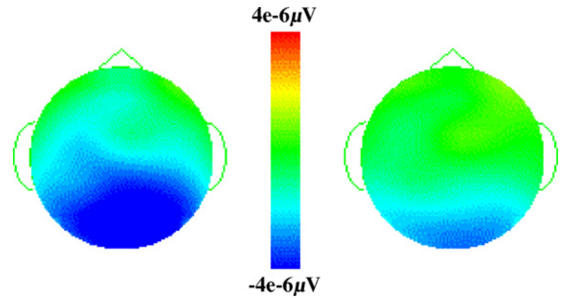

Fig. 3. Topographic distribution of ERP voltage differences (200–800 ms) between 'Remember' responses and correct rejections (left) and 'Know' responses and correct rejections (right).

'Remember' versus correct rejections. A main effect of response type [$F(1,26) = 23.83$, $p < 0.001$, $\eta^2 = 0.48$] reflected that 'Remember' responses were more negative than correct rejections. This effect was modified by site [$F(4,104) = 15.45$, $p < 0.001$, $\eta^2 = 0.37$], as it was clearly largest at parieto-occipital sites.

'Know' versus correct rejections. There was a main effect of response type [$F(1,26) = 5.72$, $p = 0.024$, $\eta^2 = 0.18$], indicating that 'Know' responses were more negative than correct rejections. This effect was also modified by site [$F(4,104) = 14.65$, $p < 0.001$, $\eta^2 = 0.36$] with the effect of response type largest at parieto-occipital sites.

'Know' versus 'Remember'. Again, there was a main effect of response type [$F(1,26) = 13.94$, $p < 0.001$, $\eta^2 = 0.35$] and a response type x site interaction [$F(14,104) = 4.45$, $p = 0.017$, $\eta^2 = 0.15$]. These effects indicate that 'Remember' responses were more negative than 'Know' responses, particularly at central, parietal and occipital sites.

4. Discussion

By time-locking ERP responses to the initial Old/New decisions (instead of to the presentation of test item), the processing involved in making subsequent Remember/Know decisions could be evaluated. Using this methodology, we found a posterior negativity associated with 'Remember' relative to 'Know' responses and both 'Remember' and 'Know' responses relative to correct rejections. Note that this negativity did not differentiate these response types when they were time-locked to test item presentation (see Fig. 4). Thus, the present analysis provides additional insight into the neural correlates of Remember/Know decisions.

Recent recognition memory studies, particularly those involving source judgments, have reported a negative wave, the LPN, with a similar topography to the current results. It has been hypothesized that the LPN is related to the recapitulation of study details at test (Cycowicz and Friedman, 2003; Friedman et al., 2005; Johansson and Mecklinger, 2003; Li et al., 2004). This processing is thought to reflect the search for and representation of bound features of a prior study episode. Its parieto-occipital location and association with study tasks in which items are presented in the visual modality have led to the suggestion that the LPN is specific to recapitulation of visual

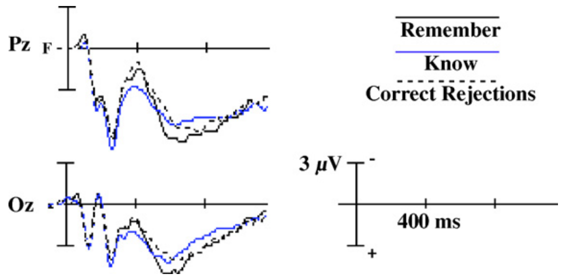

Fig. 4. Grand average ERP plots for ‘Remember’ responses, ‘Know’ responses and correct rejections time-locked to test item presentation (indicated by the large vertical “I”) at posterior sites. Note that with this time-locking, there is no evidence of a negative wave associated with ‘Remember’ or ‘Know’ responses.

features, analogous to primary visual area activations associated with retrieval in fMRI studies (e.g., Slotnick and Schacter, 2004).

In the Remember/Know paradigm, participants are instructed to endorse recognized items as ‘Remember’ when they retrieve contextual details of the prior study episode. If the negative wave we found reflects the same processing as the LPN, this suggests that participants search for features (including visual) of the prior study episode to make the Remember/Know determination. For example, if the subject retrieves the visual presentation of test word at study with, perhaps, other bound contextual features, such as his or her location in the ERP laboratory, the item could then be endorsed with a “Remember” response. Such processing would be consistent with how subjects are instructed to distinguish remembered from known items. It is also worth noting that Chua et al. (2006) in a recent fMRI study reported medial and lateral parietal activations associated with the process of confidence assessment. It is possible that the posteriorly distributed ERP differences found here associated with Remember/Know assessment represent overlapping neural activity with that involved in confidence judgments.

An interesting aspect of the current data is that ‘Know’ responses were associated with a posterior negativity, intermediate between ‘Remember’ responses and correct rejections; that is, the differences among these neural responses were quantitative rather than qualitative. This result appears to go against the subjective experience that remembering and knowing seem qualitatively different. There are several possible explanations for this apparent discrepancy. In our previous paper that analysed our experimental data time-locked to the test item presentation, qualitatively different ERP signatures were observed between ‘Old’ responses followed by a ‘Remember’ response and ‘Old’ responses that were followed by a ‘Know’ response (see Figs. 4 and 5 of Wolk et al., 2006), consistent with prior work in the ERP literature (Duarte et al., 2004; Duzel et al., 1997). One possibility is that the underlying neural correlates of remembering and knowing have largely finished by the time the metamemorial Remember/Know decision is made. The subsequent observed activity in this study may then be related to the introspective decision made by the subject as to whether the retrieved information contains the rich contextual details associated with remembering, or the more impoverished memory of familiarity. Recollection and familiarity may each contribute to retrieval of perceptual information, with recollection producing relatively greater perceptual information than familiarity. Another possibility to explain the quantitative nature of these effects is that the posterior negativity correlates with both the search attempt and representation of retrieved features. Because ‘Know’ responses would be associated with failed attempts to represent contextual details, the amplitude of this wave would be reduced relative to ‘Remember’ responses. However, some work has suggested that the posterior negativity is not dependent at all on success, but is a correlate of a search attempt (Friedman et al., 2005). For ‘Know’ responses, participants may have only attempted to retrieve contextual details for a portion of these items, perhaps based on the strength of the initial memory trace, resulting in a dilution of the LPN amplitude. Lastly, although there is much evidence for the dual process theory of memory, these quantitative differences could also be interpreted as supporting a single process model, with the difference between remembering and knowing being solely related to the amount of perceptual information retrieved from memory. Additional studies will be needed to answer this interesting question.

Future studies can use the current methodology to examine this hypothesis, as well as additional theoretical issues concerning the neural underpinnings of Remember/Know decisions and other meta-memory judgments. The temporal resolution of ERP allows it to be particularly well-suited for isolating cognitive processes related to such judgments. In combination with more spatially resolute methodologies (e.g., fMRI) a fuller understanding of how one assesses their own memory may be achieved. Chua et al. (2006) have demonstrated that research into this type of metamemorial process is feasible using fMRI. Additional work in this field will help to determine whether the medial and lateral parietal activations observed in their study to be associated with the process of confidence assessment would also be observed in making a Remember/Know determination.

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