

To investigate brain mechanisms involved in identifying the origin of memories, event-related potentials (ERPs) were recorded as participants discriminated previously presented (old) from new items or identified their earlier source (picture, word, or new). Differences in ERPs between old–new recognition and source identification were focused at frontal sites. For source identification, prominent negative deflections at occipital or frontal sites occurred depending on encoding task. These results support a model in which memory attributes are distributed neocortically and the frontal lobes are critical for source monitoring.

Key words: Distributed memory; Event-related potentials; Frontal lobe function; Reality monitoring; Recognition memory; Source monitoring

Electrophysiological brain activity and memory source monitoring

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Introduction

People sometimes confuse memories for perceived and imagined events.¹ Such reality monitoring errors can have profound consequences, as in erroneous eyewitness testimony or false memories of sexual abuse.^{2–4} Understanding how such confusions might occur can benefit from a cognitive model of how people normally discriminate information from various sources when remembering. Johnson and colleagues^{1,4} proposed such a source monitoring framework (SMF). Consistent with the SMF, behavioral studies suggest that people attribute memories to sources by evaluating various qualities of their memories such as records of the cognitive operations (e.g. imaging, comparing, searching) that were engaged when the memory was established and records of the type and amount of perceptual and contextual detail.^{1,4} Researchers have proposed that such memorial information is stored throughout the neocortex in the regions involved in the initial perceptual/cognitive processing,^{5–9} and that the frontal lobes play an important role in the retrieval and evaluation of such information.^{10–12} Measures of blood flow using positron emission tomography (PET) support the idea that the frontal lobes are involved in event memory tasks such as discriminating recently presented words from words that were not recently presented (old–new recognition).¹³ Because old–new recognition involves a type of source discrimination,⁴ these results constitute indirect evidence of general frontal involvement in source monitoring. Source

memory deficits in patients with frontal lesions provide additional evidence.^{14–16}

The present study provides converging evidence from normal subjects by showing that frontal scalp event-related potentials (ERPs) reflect different source monitoring demands. More important, the present study provides new evidence supporting the notion that distributed records of particular memory attributes stored in specific neocortical areas are consulted in source monitoring.

Materials and Methods

The study was approved by the Princeton University Institutional Review Board and participants signed consent forms after the procedures were explained. Sixteen male and 16 female university students saw 52 words and 52 line drawings presented randomly on a computer screen at a rate of one item every 8 s. Across participants, an item was equally likely to be presented as a picture or a word. Participants in the Artist condition ($n = 16$) rated how difficult it would be for an artist to draw the presented picture or a picture they imagined based on the presented word. Participants in the Function condition ($n = 16$) rated the number of functions they could generate for each item. Participants are likely to generate images on word trials in both conditions, but those purposefully generated in the Artist condition should include more pictorial information and yield more records of image-generation cognitive operations than those spontaneously generated in the

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Function condition. The Function condition should yield more stored abstract semantic information and associated cognitive operations records than the Artist condition.¹⁰

After a 5 min rest, participants were tested while ERPs were recorded from scalp electrodes. Half the participants in each encoding condition (Artist, Function) received an old–new recognition test and half received a source identification test. In both, subjects viewed the same random list of word stimuli corresponding to previously seen pictures or words, or new items. In the old–new condition, participants pressed one button ('old') if a test item corresponded to a previous picture or word, and another if not ('new'). In the source identification task, participants pressed separate buttons corresponding to 'picture', 'word', or 'new' for each item. The old–new task should be an easier source monitoring task than the source identification task because in the old–new task recency or non-specific familiarity may suffice to distinguish old from new items; in the source identification task, recency/familiarity is insufficient. More specific information is required to discriminate source (picture *vs* word).^{17,18}

Electroencephalograms were measured via 32 cap-mounted tin electrodes (left-mastoid reference), including two eye channels for ocular artifact rejection. Reference quietness was ascertained by checking right-mastoid activity. Electrode impedances were < 5 k Ω .

Signals were amplified 20 000 \times (high/low-pass: 0.01/100 Hz) and digitized on-line at 250 Hz. Individual subject ERPs were digitally filtered (low-pass cut-off: 20 Hz). ERPs were computed off-line from artifact-free trials using a 100 ms prestimulus baseline and a 1948 ms epoch. ERP amplitudes were subjected to analysis of variance using the Greenhouse–Geisser correction where appropriate,¹⁹ and confirmed with analysis of normalized data for interactions involving electrode site.²⁰

Each test trial consisted of a fixation cross (1000 ms), test word (200 ms), a response interval (3800 ms) and an 'OK to blink' message (3000 ms). Figures 1 and 2 show stimulus-locked grand-average ERPs. Stimulus onset starts at the vertical tick at the left of the horizontal time-axis (incremented by 100 ms ticks shown on the time scale). Positive voltages are plotted up.

Results and Discussion

The mean proportion correct responses and mean response time (in parentheses) was 0.86 (1221 ms) and 0.90 (1093 ms) for the Artist/old–new and the Function/old–new conditions, respectively. The proportion of correct source identifications (picture,

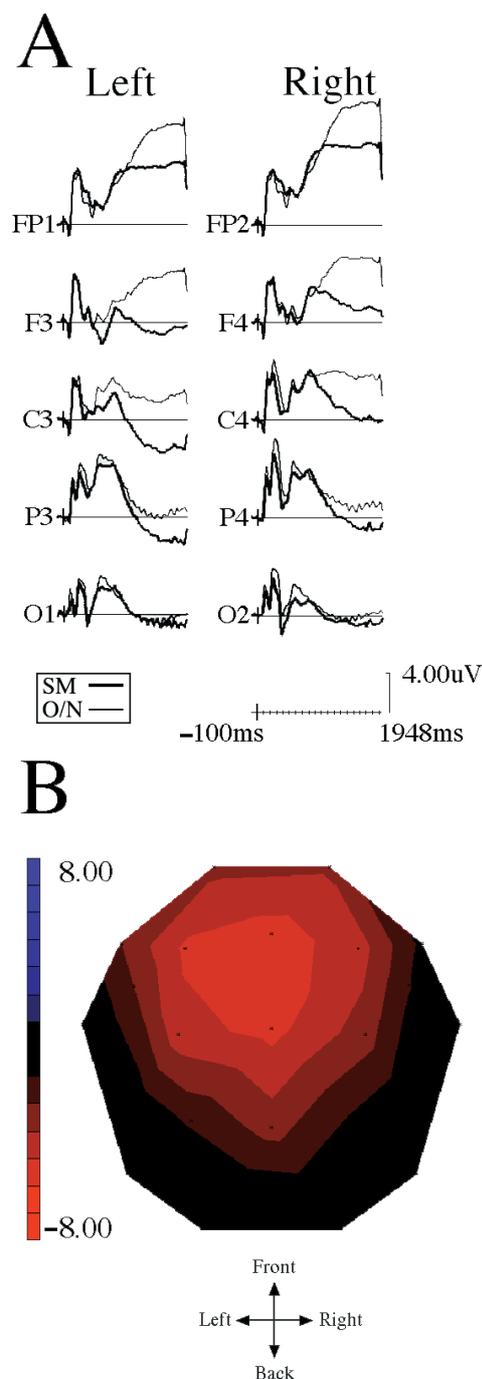


FIG 1. (A) Mean ERP amplitudes at selected electrode sites for old-new recognition and source identification (SM) conditions (averaged across Artist and Function conditions). (B) Mean ERP amplitudes (1400 ms post-test stimulus) in old-new recognition condition subtracted from mean ERP amplitudes in source identification condition, for each of 28 electrode sites.

word, new) and mean response time was 0.78 (1758 ms) and 0.85 (1715 ms) for the Artist/source and Function/source conditions.

Figure 1A shows ERPs (averaged across encoding conditions but shown separately for old–new and source tests) for correct responses at selected sites:

left/right frontal pole (FP1/2), frontal (F3/4), central (C3/4), parietal (P3/4) and occipital (O1/2). Separate test (old–new, source) \times site (FP, F, C, P, O) \times hemisphere (L, R) analyses of variance were conducted on amplitudes averaged for early (300–500 ms) and late (1300–1500 ms) post-stimulus intervals. At the early interval, there were no significant effects of test ($p < 0.43$). In contrast, at the late interval there was a test \times site interaction ($F(4,112) = 4.01$, $MSe = 16.43$, $p < 0.03$). Thus, there was a marked difference between old–new and source conditions emerging late during a trial at frontal sites, while the waveforms for the two tasks were similar at posterior sites. Figure 1B is a topographic map representing the difference between waves in the source and old–new tasks at 1400 ms post-test stimulus for 28 electrodes. The pattern shown in figure 1A and 1B is consistent with the idea that source identification requires a more complex evaluation than old–new recognition and that it is more dependent on frontal lobe functions, as also suggested by evidence from patients with brain damage.^{14–16}

There was also a significant site \times hemisphere interaction in the late interval ($F(4,112) = 11.46$, $MSe = 1.91$, $p < 0.001$) but not in the early interval ($p > 0.09$ for normalized data). There was greater positivity over the right hemisphere than the left and the asymmetry was larger over anterior sites than posterior sites, consistent with recent PET²¹ and ERP findings.²² This pattern suggests that asymmetries in PET episodic memory studies (which require averaging over time intervals of several seconds) reflect processing differences that emerge over time during a trial as memories are revived and evaluated.¹⁸

Figure 2A shows the waveforms for the source identification task separately for the Artist and Function conditions. For both, participants decided whether each test word corresponded to a previous picture or word, or was a new item. Although the stimuli and task were identical in these two conditions, there was a striking difference in ERPs, reflected in a significant site \times condition interaction at the early interval ($F(4,56) = 9.51$, $MSe = 18.62$, $p < 0.001$). The Artist subjects showed a distinct negative deflection at approximately 450 ms focused at frontal sites. In contrast, the function group showed a distinct negative deflection at approximately 375 ms at occipital sites. There was no such site \times condition interaction in the early interval for the old–new condition. Figures 2B and 2C are topographic maps depicting the ERP amplitudes for 28 electrode sites at the temporal focus of the frontal negativity for the Artist condition and the temporal focus of the occipital negativity for the Function condition. The results in figure 2 show that the distribution of ERP activity depends on what was

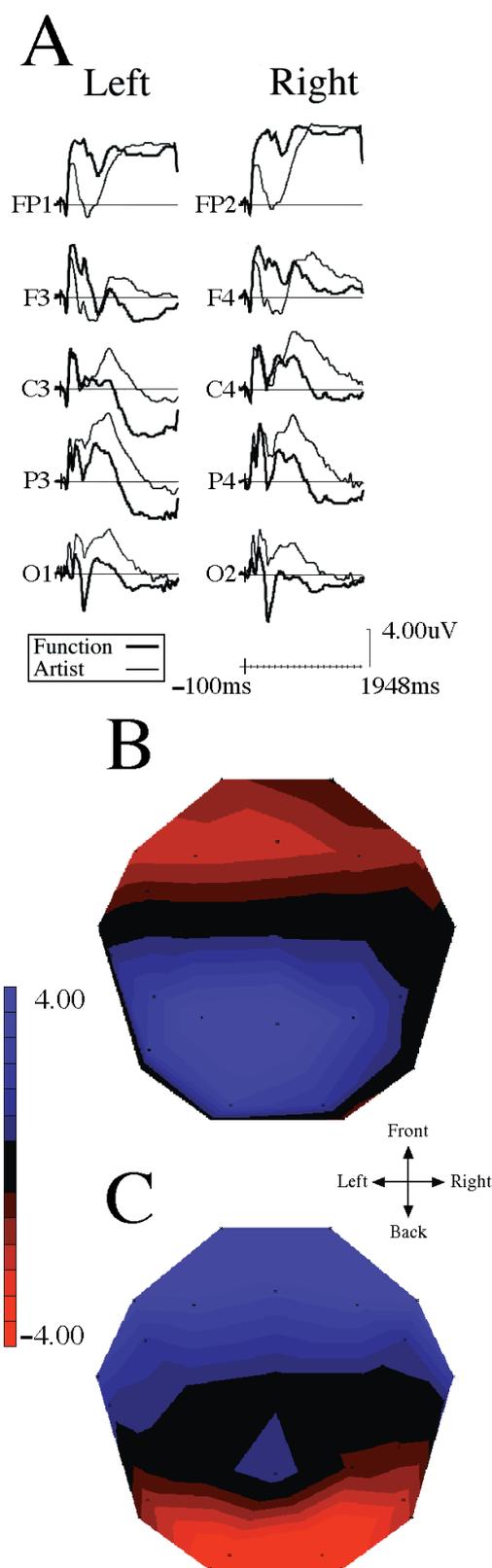


FIG. 2. (A) Mean ERP amplitudes at selected electrode sites for the Artist and Function source identification conditions. (B,C) Mean ERP amplitudes in the source identification condition for each of 28 electrode sites at post-stimulus peak negativity (red area) in the Artist (B) and Function (C) conditions.

initially encoded and, we hypothesize, what information subjects were consulting during the source monitoring test.

This difference in scalp distribution for negative deflections occurring in the same general time frame is consistent with the idea that brain activity in a source monitoring task depends on what kind of information is being accessed and/or weighted most heavily, as suggested by the SMF. One hypothesis is that for the Function group the amount of perceptual detail is a good cue about the source of memories because memories with little perceptual detail are more likely to have been derived from words and memories with a large amount of perceptual detail are likely to have been derived from pictures. Function subjects therefore probe primarily for pictorial information stored in posterior visual cortex,²³ hence the occipital negativity. In contrast, perceptual detail should not be as good a source cue for Artist subjects because images generated for the words should include considerable (imagined) perceptual information, making them more similar to perceived pictures along this dimension. Artist subjects might therefore be more likely to probe for stored records of the cognitive operations used to generate images (as opposed to perceiving pictures). Accessing records of such self-initiated cognitive operations hypothetically involves frontal lobe activity, hence the frontal negativities for Artist subjects.¹⁰

The marked negative deflections over frontal and occipital sites that differentiated the Artist and Function groups occurred for new items as well as old items. Presumably, new items typically evoke less target information than old items but they must be subjected to the same evaluative operations (e.g. noting the amount of perceptual information they activate). These data suggest that the distribution of these prominent negative ERP components may be associated with the type of information queried in the task, not necessarily with the information available in memory. The relation between the negative deflections reported here and the N400s observed in different cognitive paradigms^{24,25} remains to be explored. For example, negativities are correlated with violations of semantic context and may index additional processing requirements. In the present experiment, the negative deflections may be indexing differential contextually-based accessing and weighting of qualitatively different types of memorial information represented in various neocortical areas, in accord with the SMF.

Conclusion

The striking waveform differences under identical testing conditions during source monitoring for the

Artist and Function groups provide direct support for proposals that differentiated features of memories are distributed throughout neocortex (Fig. 2B,C). These results also show that what individuals are trying to do – their ‘agenda’ – affects the processes engaged and/or features that are activated or evaluated. The prominent negativities shown in figure 2B and C were present when subjects made source judgments but not when they made old–new judgments, although the stimuli were identical in the two cases. Furthermore, consistent with evidence from brain lesion patients, activity recorded at frontal sites distinguishes old–new recognition and source identification (Fig. 1B). Finally, anterior *vs* posterior differences in activity and hemispheric asymmetries found with PET were replicated; the ERP findings further show that these anterior/posterior differences and asymmetries develop over the time course of individual trials as information is accessed or evaluated. Although the spatial localization of ERPs is currently crude compared with PET or fMRI, the extremely high temporal resolution of ERPs can clarify the brain mechanisms underlying the cognitive processes by which individuals discriminate and confuse the origin of information in memory.

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