Memory Encoding and Retrieval in the Aging Brain

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ABSTRACT
Decline in episodic memory, the encoding and retrieval of autobiographical events, is a hallmark of normal cognitive aging. Although the primary causes of this decline remain elusive, event-related brain potential (ERP) studies have contributed to an understanding of age-related episodic memory failure. These data reveal that, although the retrieval-based episodic memory (EM) effect does not differ dramatically between young and older adults, the acquisition-related data suggest a decline in episodic encoding (i.e., semantic elaboration) with increasing age. We conclude that, at the current state of knowledge, encoding deficiencies are more important than retrieval deficits in understanding the causes of episodic memory decline in the older adult.

INTRODUCTION
The study of how humans encode, store and retrieve mnemonic information has had a long scientific history, beginning formally with the classical studies of Ebbinghaus in the late 19th century. The relatively recent development of techniques allowing the investigation of how these processes are instantiated in the brain has provided an unprecedented in vivo window on mnemonic function in the actively performing human. Although much has been learned about how (by which brain networks) memories are encoded and retrieved in the normal young adult, relatively less is known about how aging affects the functioning of these different processes. Normal aging is accompanied by well-documented failures in episodic memory, although their root causes are unclear. Understanding the sources of encoding and/or retrieval difficulties is, therefore, critical to a more comprehensive knowledge of episodic memory function in old age and, eventually, for designing remedial programs aimed at ameliorating mnemonic deficiencies in the elderly.

Two brain imaging technologies have been used to chart changes in episodic memory in normally aging older adults, event-related brain potentials (ERPs) and event-related functional magnetic resonance imaging (fMRI). Although the fMRI technique is highly accurate in localizing areas of activation within the brain, the sluggishness of the hemodynamic response makes it impossible to determine precisely the temporal sequence and duration of brain region activations. By contrast, the ERP method enables the collection of very precise temporal information, at the cost of less accurate spatial resolution than fMRI. The ERP technique, therefore, enables the viewing of brain activity related to the formation and retrieval of memories in temporal units that are consistent with the speed of cognitive processes, i.e., milliseconds. Hence, ERP studies of cognitive aging can provide detailed information on age-related differences in the timing and duration of specific mnemonic processes that contribute to encoding and retrieval. Episodic memory is comprised of personal memories that include specific spatio-temporal information about the context in which the event occurred. Episodic memory is investigated most often using paradigms that assess recognition memory. In these paradigms, participants are tested by asking them to judge whether each item was encountered previously during an encoding (i.e., study) phase or is new. Recognition memory is generally thought to rely on two processes, one relatively automatic and fast-acting, labeled familiarity, and the other, more effortful, slower and requiring conscious deliberation, labeled recollection. For example, one can recognize with certainty a person’s face as having been seen before, but not be able to recall the contextual details that accompanied the initial episode (i.e., where and when the person was initially encountered). This is an instance of a recognition judgment based on familiarity in the absence of recollection. Given that the contextual details were encoded during the original event and an efficient retrieval strategy, the missing features can often be recalled and reintegrated with the information provided by the face (i.e., recollected), resulting in a reconstructed episodic memory.

Because the retrieval of episodes depends upon how the information was initially encoded, we first review stud-
ies of ERP activity recorded during encoding phases for subsequent recognition testing. We then review the results of ERP investigations of retrieval.

**Encoding-related studies**

Relative to non-semantic, or shallow encoding (for example, processing orthographic features of words), semantic or deep encoding (as when making living/non-living judgments about words) leads to a greater likelihood that those words will be recognized on a subsequent memory test. By now, a large number of studies have shown that the degree to which an item’s memory trace is enriched during encoding is determined by the amount one elaborates upon the information retrieved from semantic memory, a phenomenon that can be labeled episodic encoding. Hence, semantic retrieval and episodic encoding appear to work in tandem, perhaps with semantic retrieval occurring prior to episodic encoding.

ERP investigators have assessed encoding-related processing by quantifying the differences in neural activity associated with individual items during an encoding phase based on whether or not those items are subsequently remembered. A subtraction of the ERPs elicited by study items that are subsequently forgotten from those that are subsequently remembered yields the subsequent memory effect (SME), a measure of encoding. SMEs usually, but not always, have a positive polarity that is widely distributed across the scalp. In their investigation, Paller and colleagues had subjects encode words under deep (e.g., is it living?) and shallow (e.g., does the word contain 2 vowels?) conditions. In accord with Craik and Lockhart, semantic encoding engendered higher rates of recognition success compared to non-semantic encoding. Importantly, SMEs, which onset at roughly 400 ms and lasted about 600 ms, were reliable under semantic but not non-semantic conditions. Hence, SMEs have been associated with semantic encoding activity because their magnitude is positively related to the extent of deep encoding processes during acquisition. The question arises, however, as to whether SMEs are related to subsequent recollection compared to familiarity-based retrievals.

One method by which the distinction between recollection and familiarity has been demonstrated is with the “Remember/Know” paradigm. In this paradigm, for items judged old, subjects indicate whether their recognition decision was accompanied by the retrieval of contextual detail, a “remember” (R) judgment (i.e., a recollection-based retrieval), or was based on a feeling of familiarity with the item, a “know” (K) judgment (i.e., a familiarity-based retrieval). Moreover, items that are deeply encoded are associated subsequently with a greater proportion of R judgments, whereas items that are shallowly encoded are associated subsequently with a greater proportion of K responses.

The R/K paradigm was used by Friedman and Trott to assess whether recollection- and familiarity-based retrievals had their origin during encoding. During the study phase, participants were asked to memorize two nouns embedded in sentences for a subsequent recognition test. During the recognition test, subjects decided whether nouns were new or old and, for old nouns, made an additional R/K judgment. The study phase ERPs were averaged into three classes on the basis of subsequent recognition performance: 1) subsequently correctly recognized and given an R judgment, 2) subsequently correctly recognized and given a K judgment, and 3) subsequently unrecognized (i.e., a miss). SMEs were computed by subtracting the ERPs associated with subsequently missed items from those associated with subsequent R and K judgments. For young adults, reliable SMEs were observed in the interval from 400 - 900 ms for study items associated with subsequent R judgments but not subsequent K judgments. These SME data suggest that recollection- and familiarity-based recognition judgments at retrieval had their origin in the type of encoding activity engaged in during study.

In addition to young adult participants, Friedman and Trott recruited older adults. There was some basis for expecting age-related differences in ERP activity because the elderly had been shown to produce a smaller percentage of remember judgments than the young, and to rely more on familiarity than recollection when these two processes are placed in opposition. Both findings suggest an age-related imbalance in the recollective component of recognition memory. Hence, Friedman and Trott determined whether aging interacted with the familiarity/recollection distinction in modulating encoding-related ERP activity. Compared with the data of the young described above, for the elderly, reliable SMEs were observed in association with both subsequent R and K judgments. Friedman and Trott concluded that, during the study phase, older subjects did not differentially encode those items that would be subsequently associated with retrieval of contextual details (remember) from those that would not (know). Furthermore, these data implicated age-related deficits in encoding as contributing to episodic memory deficits in the elderly.

These conclusions received some support from the distribution of SME activity across the scalp. For the young, in addition to positive electrical activity, the SME for R judgments was associated with negative activity over left inferior or prefrontal scalp (LIPFS); there was no evidence of negative activity over LIPFS in the data of the elderly. The negative activity could have reflected retrieval of information from semantic memory, as R. Johnson and coworkers observed negative-going ERP activity over LIPFS in association with semantic but not orthographic decisions. Such results fit well with those of hemodynamic studies showing that the retrieval of semantic memories and the encoding of episodic memories depend upon activity in regions of the LIPFC. Assuming that the blood flow and ERP data share at least some common
brain generators, together they suggest that the older adults of the Friedman and Trott investigation\textsuperscript{17} may have been impaired in semantic encoding, which could have been responsible for their lower recognition success.

Supporting evidence for this conclusion has come from behavioral investigations documenting that older adults, in the absence of a specific encoding strategy, do not use semantic elaboration spontaneously.\textsuperscript{17} Hence, because volunteers in the Friedman and Trott\textsuperscript{17} investigation were asked simply to memorize the nouns without any specific encoding instructions, it is difficult to determine from those data whether the putative encoding deficiency in the elderly was due to a failure of semantic retrieval, a failure of episodic encoding or both.

To investigate further the nature of encoding processes in the elderly, Nessler and colleagues\textsuperscript{18,19} exerted greater control over the use of encoding strategies with a semantic selection paradigm adapted from Thompson-Schill and coworkers.\textsuperscript{20} In our modified version of the object classification task described by Thompson-Schill et al.,\textsuperscript{20} young and older participants were asked to study words under Low- and High-selection conditions. The Low-selection task required a decision as to whether a previously presented picture (e.g., lion) matched the meaning of a to-be-remembered word (e.g., lion). In the High-selection condition, by contrast, a decision was made concerning whether a previously presented adjective (e.g., heavy) described a feature of the to-be-remembered word (e.g., feather). While both decisions necessitated the retrieval of the semantic concept, the High-selection decision required, in addition, the selection of specific semantic features from several alternatives. This design enabled us to assess age-related changes in ERP activity under conditions in which young and old participants engaged in qualitatively similar types of encoding activity (see Rugg and Morcom\textsuperscript{21} for other methodological issues in ERP research on aging). Following the encoding phase, a recognition test on the items studied under Low- and High-selection conditions enabled us to determine whether the age-related decline in recognition memory was due to failures in semantic retrieval/selection and/or episodic encoding.

During the encoding phase, older adults performed as well as the young adults, indicating that they were well able to retrieve semantic information and select among competing alternatives in the High-selection condition. However, during the subsequent recognition test, older adults performed reliably more poorly than the young adults. Figure 1 depicts the encoding-related ERP activity elicited over LIPFS in the young and elderly adults obtained by subtracting the activity elicited in the Low-selection condition from that elicited in the High-selection condition. These difference waveforms show for both young and old adults significant negative activity in the early period (400-800 ms) over LIPFS. This selection-related effect is sustained in the young adult data into the late time interval (1200-1400 ms), but dramatically attenuated in the older adult waveforms. Additionally, the young show greater negativity than the elderly in the early interval. Hence, there appear to be three
negativities: an early, selection-related activity present in both young and old ERPs; an additional, early negativity present only in the waveforms of the young; and a late, selection-related negativity, again present only in the ERPs of the young. Consistent with their equivalent behavioral performance, the magnitude of the early, selection-related negativity was the same in the young and elderly, suggesting that this brain activity reflects semantic retrieval/selection. As the young outperformed the elderly during recognition testing, the additional early negativity and the late negativity presumably reflect episodic encoding, i.e., additional semantic elaboration performed on the products of semantic retrieval/selection. On this view, our data support the conclusion that the episodic memory deficit in the elderly in the current paradigm is a result of a failure to engage in additional episodic encoding which would have resulted in more richly encoded memory traces, thereby ensuring a higher rate of successful retrieval. The topographic maps illustrated in Figure 1 (right panel) demonstrate dramatically attenuated negative activity in the late interval over LIFPS for the elderly. Hence, the hemodynamic data reviewed earlier and these topographic data suggest that the age-related encoding difficulties may have resulted from a failure to activate LIFPC in the late interval.

The Friedman and Trott\(^1\) and Nessler et al.\(^9\) data suggest that encoding deficits may underlie the well-documented episodic memory decline in elderly samples. We turn now to a consideration of ERP data recorded at retrieval.

**Retrieval-related studies**

Recognition processes can be studied by separately averaging the ERP activity elicited by old items that are correctly recognized (i.e., hits) and new items that are correctly rejected. A subtraction of the latter from the former reveals the episodic memory (EM) effect, an index of retrieval.\(^2\) In young adults, a series of EM effects with distinct temporal and topographic patterns have been observed fairly consistently in many investigations of recognition memory, suggesting that they reflect unique stages of mnemonic processing.\(^2\) For example, relatively early in the retrieval process, between approximately 300 and 500 ms, a medial frontal, positive-going, EM effect has been associated with the familiarity component of recognition memory. This association with familiarity is based upon observations that its amplitude is similar to 1) correctly recognized old items regardless of whether they are endorsed with remember or know judgments; 2) correctly recognized old items regardless of whether the contextual details from the original episode are correctly identified; and 3) correctly recognized old items and falsely recognized items that are highly similar to the previously studied old items, i.e., "lures."\(^24\)

On the other hand, later in the retrieval sequence, a subsequent left parietal, positive-going, EM effect (500-800 ms) has been associated with recollection, as its amplitude is larger to 1) correctly recognized old items associated with remember compared to know judgments; 2) correctly recognized old items associated with correct compared to incorrect source judgments; and 3) correctly recognized old items compared to falsely recognized, highly similar lure items.\(^25\) Consistent with the medial prefrontal and left parietal EM effects reflecting distinct mnemonic processes, recent data have indicated that they are associated with reliably different scalp distributions, suggesting different intracranial generators.\(^24,25,26\)

Later-onsetting, longer duration EM effects have also been reported. For example, an asymmetric, positive, right prefrontal EM effect has been observed, although a consensus regarding its functional significance has yet to be arrived at. It onsets roughly with the diminution of the left parietal EM effect and reaches peak amplitude typically following mean reaction time for the old/new recognition decision. The post-response timing of this component has led some authors to suggest that it may reflect a cognitive control function, such as evaluating the products of retrieval to support ongoing memory performance.\(^30\)

Based on the finding that the elderly rely more on familiarity than recollection, and assuming that the medial prefrontal EM effect reflects familiarity-based processing, one expectation is that this EM effect would be of similar magnitude in the ERPs of the young and elderly. Unfortunately, few studies have directly assessed age-related changes in the medial prefrontal EM effect. In the Remember/Know study of Trott et al.\(^22\) described above, the medial prefrontal EM effect (300-500 ms) was of similar magnitude and topography in the young and old adult waveforms in association with correctly recognized old items given either R or K judgments (see also Wegesin et al.\(^1\)). Along with a similar percentage of old items attracting know judgments in the young and elderly, these limited ERP data suggest an intact familiarity mechanism in the elderly.

By contrast with the paucity of data on age-related changes in the medial prefrontal EM effect, somewhat more is known about the left parietal EM effect. Based on the behavioral literature emphasizing age-related deficits in recollection and the ERP data reviewed earlier suggesting that the left parietal EM effect indexes contextual retrieval, one might expect smaller-magnitude left parietal EM effects in the ERPs of the elderly compared to those of the young. To the contrary, this has generally not proven to be the case. Initial investigations by Friedman et al.\(^2\) and Rugg\(^10\) and Swick and Knight\(^4\) did not use behavioral indices presumed to reflect familiarity and recollection. In later studies, however, measures considered proxies for recollection and familiarity were collected and, hence, the results of these investigations provide a firmer basis for conclusions about aging effects on the left parietal EM effect. Both Mark and Rugg\(^16\) and Trott et al.\(^23\) solicited R and K as well as source judgments from young and older adults. In both investigations,
the left parietal EM effect in response to correctly recognized old items attracting R judgments (or correct source judgments) did not differ in magnitude or scalp topography between young and older adults. Similar phenomena were observed by Wegesin and coworkers.\(^{21}\) Despite this similarity, in all of these investigations older adults showed greater decrements in source compared to item memory relative to young adults.\(^{21}\) Moreover, the temporal precision of the ERP method enabled the investigators in all three studies to determine that the EM effects were prolonged in older adults by about 100 ms relative to those of the young. This finding appears to be consistent with the cognitive slowing that is typically observed in older adults.\(^{27}\) Although limited, these data collectively suggest that, to the extent that the left parietal EM effect reflects the retrieval of source-specific information, older adults, albeit with prolonged processing time, do not appear to differ from young adults in this aspect of memory retrieval.

The results of age-related investigations of the right-prefrontal EM effect are not at all in agreement. This may not be surprising given the somewhat imprecise definition of "post-retrieval processing" that has been ascribed to this EM effect. In two studies of recognition memory with source judgments, Trott and colleagues\(^{22}\) and Wegesin et al\(^{21}\) observed robust right prefrontal EM effects in their young adult participants but failed to find similar activity in the waveforms of their older adults. On the other hand, Mark and Rugg\(^{26}\) and Li et al.,\(^{24}\) also in source memory paradigms, did observe reliable right prefrontal EM effects in their older adult waveforms. Given the elusive nature of the behavioral correlates of this EM effect and the contradictory age-related findings, it is difficult to comment with any confidence on the import of this EM effect in understanding age-associated changes in episodic memory.

CONCLUSIONS

Clearly, there are too few age-related ERP studies of episodic memory to permit firm conclusions. Nevertheless, some tentative implications of the studies reviewed here can be advanced. The available data suggest that encoding deficiencies may play a larger role in influencing episodic memory deficits in older adults. This interpretation is consistent with the results of divided attention studies, which demonstrate greater episodic memory deficits in both young and elderly adults when attention is divided at encoding, with a concomitant decrease in LIPFC activity, compared to when it is divided at retrieval.\(^{26}\) The encoding-related data of Friedman and Trott\(^{11}\) and Nessler and colleagues\(^{18,19}\) suggest that an underlying mechanism may be a lack of spontaneous elaboration of the products retrieved during semantic processing (i.e., episodic encoding) perhaps resulting from a failure to recruit LIPFC. The limited, retrieval-based ERP data suggest relatively intact familiarity- and recollection-based processing in the elderly. However, this does not account for the consistently poorer source memory performance of older relative to younger adults despite similar-magnitude, left parietal EM effects in young and elderly samples. This disparity suggests that, in addition to encoding deficiencies, other, as yet under- or un-explored, retrieval mechanisms might contribute to this episodic memory deficit. For example, age-related differences in retrieval orientation, the differential processing of test items according to how the items were studied, have recently been demonstrated.\(^{41}\) Further study of this type of phenomenon and its impact on age-related episodic memory decline is clearly warranted. Additionally, future work needs to address current gaps in knowledge by recording ERP activity during both encoding and retrieval phases. Although older adults may not spontaneously elaborate upon the products of semantic retrieval, they do benefit from increased processing demands when given an appropriate encoding strategy.\(^{18,19}\) Hence, future studies should include this type of levels of processing manipulation.\(^{8}\) These kinds of investigations will undoubtedly bring us closer to a better understanding of the root causes of age-related decline in episodic memory.

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