Effects of Age on the Neural Correlates of Retrieval Cue Processing are Modulated by Task Demands

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Abstract

■ The electrophysiological correlates of retrieval orientation—the differential processing of retrieval cues according to the nature of the sought-for information—were investigated in healthy young (18–20 years old) and older (63–77 years old) adults. In one pair of study–test cycles, subjects studied either words or pictures presented in one of two visually distinct contexts, and then performed a yes/no recognition task with words as test items. In another pair of study–test cycles, subjects again made recognition judgments, but were required, in addition, to signal the study context for each item judged "old." Young subjects' event-related potentials (ERPs) for new (unstudied) test items were more negative-going when the study material was pictures rather than words, and this effect varied little between the two retrieval tasks. Replicating a previous report [Morcom, A. M., & Rugg, M. D. Effects of age on retrieval cue processing as revealed by ERPs. *Neuropsychologia, 42,* 1525–1542, 2004], the effects of study material on the ERPs of the older subjects were attenuated and statistically nonsignificant in the recognition task. In the source retrieval task, however, material effects in the older group were comparable in both onset latency and magnitude with those of the young subjects. Thus, the failure of older adults to demonstrate differential cue processing in tests of recognition memory likely reflects the adoption of a specific retrieval strategy rather than the incapacity to process retrieval cues in a goal-directed manner. ■

INTRODUCTION

Healthy cognitive aging is characterized by a pronounced decline in episodic memory, that is, memory for unique events. The effects of age on episodic memory are particularly notable when compared to the more modest effects typically observed for other types of long-term memory such as familiarity-driven recognition memory, semantic memory, and priming (Nilsson, 2003; Craik & Jennings, 1992; Light, 1991; Craik, 1977). In an effort to understand the neural bases of age-related episodic memory impairment, numerous studies have employed noninvasive measures of neural activity, such as event-related potentials (ERPs) or functional magnetic resonance imaging (fMRI), to contrast the neural correlates of memory encoding and retrieval as a function of age (see Friedman, Nessler, & Johnson, 2007; Park & Gutchess, 2005 for recent reviews). ERP and event-related fMRI studies of retrieval have focused predominantly on the neural correlates of retrieval success, as operationalized by differences in the neural activity elicited by correctly recognized versus correctly rejected recognition memory test items (e.g., Gutchess, Ieuji, & Federmeier, 2007; Duarte, Ranganath, Trujillo, & Knight, 2006; Swick, Senkfor, & Van Petten, 2006; Li, Morcom, & Rugg, 2004; Wegesin, Friedman, Varughese, & Stern, 2002; Trott, Friedman, Ritter, Fabiani, & Snodgrass, 1999; Mark & Rugg, 1998 for ERP findings; Duverne, Habibi, & Rugg, 2007; Morcom, Li, & Rugg, 2007; Velanova, Lustig, Jacoby, & Buckner, 2007; Daselaar, Veltman, Rombouts, Raaijmakers, & Jonker, 2003 for fMRI findings).

An aspect of retrieval processing that has been relatively neglected in aging studies concerns what have been termed "preretrieval" processes—that is, processes engaged by a retrieval cue in the course of a retrieval attempt (Rugg, 2005; Rugg & Wilding, 2000). An increasing body of evidence suggests that, in young subjects at least, the processing accorded a retrieval cue can be varied according to the goal of the retrieval attempt. It has been proposed that the capacity to utilize retrieval cues in a flexible, goal-directed manner depends on the adoption of different cognitive sets—termed "retrieval orientations"—that bias cue processing in service of specific retrieval goals (Woodruff, Uncapher, & Rugg, 2006; Rugg & Wilding, 2000). It has been further proposed that the adoption of a retrieval orientation both facilitates the retrieval of relevant information from memory, and helps prevent retrieval of irrelevant information (Jacoby, Shimizu, Daniels, & Rhodes, 2005; Rugg, 2005). Therefore, an age-related decline in the ability to adopt goal-relevant retrieval orientations would likely contribute to the detrimental effects of age on episodic memory performance.

To our knowledge, only one prior behavioral study and one ERP study have investigated the effects of age on retrieval cue processing. The findings of both studies

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suggested that the capacity for differential cue processing declines with increasing age. Jacoby, Shimizu, Velanova, and Rhodes (2005) investigated the effects of age on what has been termed the ''depth of retrieval effect'' (Jacoby, Shimizu, Daniels, et al., 2005; Shimizu & Jacoby, 2005). This refers to the finding that later memory for new items encountered in the context of a recognition memory test is better when those items are intermixed with old items that had been subjected to semantic rather than nonsemantic study. The depth of retrieval effect is assumed to reflect the fact that subjects focus on the semantic attributes of retrieval cues when attempting to recognize semantically studied items, but attend to structural attributes of the cues when old items were studied nonsemantically. That is, the effect is a reflection of goal-dependent, differential cue processing (see also Rugg, Allan, & Birch, 2000). Jacoby, Shimizu, Velanova, et al. (2005) reported that older subjects fail to demonstrate a depth of retrieval effect, suggesting that the capacity for differential cue processing declines with age.

Morcom and Rugg (2004) investigated the effects of age on the ERP correlates of the differential processing of retrieval cues. In separate study–test cycles, young and older subjects encoded either visually presented words or pictures. In each case, the study phase was followed by a recognition memory test in which the retrieval cues were exclusively words. In line with previous studies in young adults (Hornberger, Rugg, & Henson, 2006; Johnson & Rugg, 2006a, 2006b; Hornberger, Morcom, & Rugg, 2004; Herron & Rugg, 2003; Robb & Rugg, 2002), the ERPs elicited by unstudied new words[1] in the young subjects of the Morcom and Rugg study were more positive-going when words were the sought-for material than when pictures were targeted. These ERP effects are assumed to reflect retrieval cue processing that differed according to the nature of the memory representations targeted with the cues (words vs. pictures). The effects were delayed and attenuated in the older subjects. Echoing the behavioral findings of Jacoby, Shimizu, Velanova, et al. (2005), these ERP findings also suggest that older adults are less likely to engage in differential processing of retrieval cues than are young subjects.

As discussed by Morcom and Rugg (2004), three explanations could account for the age-related changes in differential retrieval cue processing that they observed. First, cue processing might be less differentiated in older than in young subjects because of less distinctive encoding of the study material. According to this explanation, the effects of age on ERP correlates of differential cue processing are a consequence of the formation of memory representations that do not strongly differentiate between encoded pictures and words. Second, older adults might lack the ''cognitive flexibility'' necessary to permit the same retrieval cue to be processed in different ways. According to this account, even when different classes of memory representations are highly differentiated, older adults are unable to take advantage of this by adopting material-specific retrieval orientations. The third account stems from the proposal that older subjects, although not incapable of differential retrieval cue processing, are less likely to do so spontaneously. According to this third account, older subjects make little effort to recollect prior study episodes when confronted with simple recognition judgments, relying instead on an acontextual sense of familiarity. Hence, older adults have little incentive to process test items in a manner that optimizes the likelihood of successful recollection. Crucially, according to this third account, it should be possible to enhance differential cue processing in older adults by the employment of a retrieval task that, in contrast to simple recognition, necessitates recollection of episodic detail (see Johnson & Rugg, 2006b for a study of the impact of retrieval task demands on the ERP correlates of retrieval cue processing in young adults). By contrast, according to the first two accounts, the failure of older adults to engage in differential cue processing should be unaffected by the manipulation of retrieval task demands.

The aim of the present study was to investigate whether ERP correlates of retrieval cue processing in older adults are sensitive to the demands of the retrieval task, and hence, whether the findings of Morcom and Rugg (2004) are evidence of age-related differences in retrieval strategy, as was suggested by those authors. As in Morcom and Rugg, subjects studied lists of visually presented words or pictures, and were then immediately tested for their memory of the study items using words as retrieval cues. Unlike in the prior study, however, study items were presented in one of two distinctive contexts, and two different retrieval tasks were employed. One of these tasks required simple recognition judgments, and thus, replicated the retrieval task employed by Morcom and Rugg. The other task required a source memory judgment in addition to the recognition judgment. Unlike recognition, accurate source memory judgments require recollection of contextual information about the study episode. We expected to replicate the findings of Morcom and Rugg for the recognition task, with older adults demonstrating delayed and attenuated ERP correlates of differential cue processing relative to young subjects. The key question was whether these age-related differences in differential retrieval cue processing would be attenuated in the source memory task, consistent with the proposal that these differences reflect age effects on cue processing strategy rather than in memory encoding or cognitive flexibility.

In addition to investigating age effects on differential cue processing, we also investigated ERP correlates of successful retrieval, as operationalized by ERP ''old/new'' effects (differences in ERPs elicited by correctly recognized vs. correctly rejected test items). In the study of Morcom and Rugg (2004), it was reported that the ''left parietal'' old/new effect—a putative correlate of recollection (Rugg & Curran, 2007)—was both attenuated and distributed more bilaterally in older subjects. The present study provided an opportunity to assess the generality of this finding.

METHODS

Subjects

Sixteen healthy young adults (aged between 18 and 20 years) and 16 healthy older adults (aged between 63 and 77 years) participated in the experiment (see Table 1 for details of age and sex distribution). Data from a further four young subjects and three older subjects were rejected because of too few (<16) artifact-free trials in one or more critical experimental conditions. Data from one additional young subject and one additional older subject were discarded because of procedural problems that occurred during the experimental session. Young adults were recruited from the undergraduate and graduate student population of the University of California, Irvine, and older adults were recruited from the surrounding community. All subjects were right-handed, English native speakers, with a minimum of 12 years education and normal or corrected-to-normal vision. The subjects were free from neurological, cardiovascular, and psychiatric disease and none was taking CNS-active medication. The study was approved by the Institutional Review Board of the University of California Irvine. Informed consent was obtained at the beginning of both the ERP and neuropsychological test sessions.

Neuropsychological Testing

A battery of standardized neuropsychological tests was administered to all subjects in a separate session from the ERP procedure. The battery was intended to assess a range of cognitive functions known to either decline or to be maintained with age. The Mini-Mental State Examination was employed as a dementia screening measure. A nominal cutoff score of 26/30 was adopted, although no potential subject was rejected on the basis of this criterion. Long-term memory was assessed with the California Verbal Learning Test—II (Norman, Evans, Miller, & Heaton, 2000) and the Immediate and Delayed

Table 1. Participants' Characteristics and Raw Scores (Mean, Standard Deviation, and Ranges) on the Neuropsychological Tests

	Young Adults			*Older Adults*			
	Mean	*Standard Deviation*	*Ranges*	*Mean*	*Standard Deviation*	*Ranges*	*p*
Age	19		18–20	72		63–77	
Years of education	14.4	1.0	13–16	16.2	1.7	14–20	<.01
Mini-Mental State Examination	28.9	1.0	27–30	29.4	1.0	27–30	*ns*
CVLT[a] immediate free recall	12.2	2.6	8–16	11.1	3.0	5–15	*ns*
CVLT[a] immediate cued recall	12.6	2.0	9–16	12.3	2.1	9–15	*ns*
CVLT[a] delayed free recall	11.9	2.7	8–16	10.8	2.4	6–14	*ns*
CVLT[a] delayed cued recall	12.4	1.9	9–16	12.1	2.2	7–15	*ns*
NYU[b] paragraph immediate recall	7.4	2.6	4–10	6.8	1.8	3–10.5	*ns*
NYU[b,c] paragraph delay recall	10.7	3.3	7–19	9.1	2.2	6–11.5	*ns*
Forward/Backward Digit Span[c]	18.8	2.0	17–23	17.1	3.7	12–23	*ns*
Digit/Symbol Substitution Test	62.4	10.3	47–84	43.3	8.9	26–57	<.001
Trail Making Test A	22.9	8.8	13–48	30.8	4.2	22–40	<.01
Trail Making Test B	49.8	17.0	24–91	94.1	43.1	53–194	<.001
Letter fluency	44.2	12.0	26–81	47.0	13.2	20–73	*ns*
Category fluency	21.8	4.7	13–30	18.9	3.9	9–26	*ns*
WTAR FSIQ[d]	112.1	6.4	99–119	114.2	4.1	104–119	*ns*
Beck Depression Inventory	5.1	4.0	0–12	4.4	3.1	0–9	*ns*

[a]California Verbal Learning Test.

[b]New York University.

[c]Data available for 15 older subjects.

[d]Wechsler Test of Adult Reading Full Scale Intellectual Quotient.

NYU paragraph (Kluger, Ferris, Golomb, Mittleman, & Reisberg, 1999). Short-term memory was assessed with the Digit Span Forward and Backward test of the WAIS-R. General cognitive functions were further assessed with the Digit/Symbol Coding test of the WAIS-R, the Trail Making Test A and B, and letter fluency and category fluency tests. An estimate of full-scale IQ was obtained from the Wechsler Test of Adult Reading (WAIS-III). The Beck Depression Inventory was also administered. Data for one older subject were not obtained on the long-delay paragraph recall because of a procedural error.

Materials for ERP Study

Four study–test cycles were administered to each participant: Two cycles included a study phase comprising words, whereas the two other cycles employed pictures as study items. For each type of study material, one study–test cycle employed a recognition task and the other cycle a source memory task. Each study phase comprised 40 word names or 40 pictures. Each test phase comprised words only, and these corresponded to 40 studied and 40 unstudied items.

Overall, the experimental materials comprised a total of 320 color pictures of nameable objects and their corresponding single word names. The pictures were selected from a variety of different sources; the background and resolution were next standardized across pictures. The 320 stimuli were distributed across eight sublists of 40 stimuli. Sixteen sets of stimulus lists were created by assigning the eight sublists of stimuli to a recognition or a source task, studied or unstudied materials, study-word or study-picture materials. The assignment of the sublists to each condition was counterbalanced across the 16 sets of stimuli lists, such that a given stimulus was equally likely to appear in each condition. Additionally, each study list was buffered with two fillers at the beginning and two fillers at the end, and each test list was buffered with two unstudied fillers at its beginning.

A set of 32 additional stimuli was distributed across four practice sessions (one for each study–test cycle). Therefore, each practice comprised a study list of four items and a test list of these four studied items and four unstudied items.

Experimental Tasks and Procedure

Following electrode application (see below), the subjects were seated in a sound-attenuated recording room, about 90 cm away from the display monitor. Four study–test cycles, corresponding to the combination of the recognition and source memory tasks with words or pictures as study material, were administered. Each study–test cycle was preceded by written instructions, followed by an oral explanation and a short practice on both the study and test phases. The practice trials were repeated until subjects were comfortable with the procedure.

Half of the subjects began with two cycles of the recognition task (one cycle for each type of study material), followed by two cycles of the source task. This ordering was reversed for the remaining subjects. In addition, the ordering of study materials was counterbalanced across memory tasks. As a consequence, there were four orders of study–test cycles: ABDC, BACD, CDBA, DCAB, where A is study-word/recognition, B is study-picture/recognition, C is study-word/source, and D is study-picture/source. These orders were chosen to minimize the potential for confusion between the different tasks. Yoked pairs of young and older subjects were presented with the same combination of experimental lists in identical task orderings. Orderings were rotated across successive yoked pairs.

At study, the items were presented in one of two visual contexts: Half were presented to the left side of fixation against a green rectangular background, whereas the remainder was presented on the right side against a red background. A central fixation cross and the two colored backgrounds were displayed continuously. Each background subtended a visual angle of $9^\circ \times 14^\circ$, with a separation of 1° between their inner edges, in a field of view subtending $30^\circ \times 23^\circ$. Each study picture subtended a visual angle of approximately $5^\circ \times 5^\circ$, and was presented against a $5.5^\circ \times 5.5^\circ$ gray background. Study words subtended a maximum visual angle of $6^\circ \times 1^\circ$. Five hundred milliseconds prior to stimulus onset, the fixation cross changed color from white to blue. Each study item was presented for 1.5 sec (centered 5° lateral from fixation). After its presentation, the white central fixation cross and the two colored backgrounds remained on the screen until 1 sec after a button-press response signaling the subject's judgment.

For the study-picture conditions, the requirement was to make a judgment whether the depicted object was smaller or larger than a shoe box. For the study-word conditions, an indoor/outdoor judgment was required on the object denoted by each word. Subjects signaled their judgments by pressing one of two buttons with their right and left index fingers. The assignment of response/button to hand was counterbalanced across subjects. Subjects were encouraged to respond as quickly as possible without sacrificing accuracy. There were as many experimental objects that were unambiguously bigger or smaller than a shoe box (i.e., 47% and 47% respectively) as there were words that unambiguously denoted indoors or outdoors objects (47% and 48%, respectively). Each study list comprised equivalent numbers of unambiguous items for each type of judgment.

Each test phase began within 5 min of the preceding study phase. Test words were presented at fixation against a continuously displayed gray background that subtended a visual angle of $9^\circ \times 14^\circ$. The words subtended a maximum visual angle of $6^\circ \times 1^\circ$. Each trial began with a "+" sign at fixation for 1250 msec, followed by the test word, which was displayed for 500 msec. A "×" sign was then displayed for 2500 msec, during which subjects made an ''old/new'' recognition judgment, signaling their judgment by pressing one of two buttons with their right and left index fingers. Instructions emphasized the need to respond quickly without sacrificing accuracy and, in addition, subjects were instructed to respond ''new'' when they were uncertain if an item had been studied. In the source memory task, an additional response was required for each item judged old. The prompt ''left–green or right–red'' was displayed for 3 sec, and during this period subjects were required to signal the context in which the item had been presented at study. The hand employed for the recognition and source judgments was counterbalanced over subjects.

ERP Recording and Analysis

Electroencephalogram was recorded continuously during each test phase from 31 silver/silver–chloride electrodes. Twenty-nine of these electrodes were embedded in an elastic cap (EASYCAP; Herrsching-Breitbrunn, Germany; www.easycap.de) and two additional electrodes were placed on the left and right mastoid processes. The locations of the cap electrodes were based on the International 10–20 System (American Electroencephalographic Society, 1994) and corresponded to midline sites (Fz, Cz, Pz) and homotopic (left/right) pairs of sites (Fp1/Fp2, AF7/AF8, F3/F4, F5/F6, F7/F8, C3/C4, C5/C6, T7/T8, P3/P4, P5/P6, P7/P8, PO7/PO8, O1/O2). Vertical and horizontal electrooculograms (EOGs) were recorded from bipolar electrode pairs located above and below the left eye and on each outer canthi, respectively. Additionally, a ground electrode was embedded in the cap at the location corresponding to FCz. Electroencephalogram (recorded with reference to Cz) and EOG were acquired with a Contact Precision Instruments System (London, UK; www.psylab.com) at a 256-Hz sampling rate and an amplifier bandwidth of 0.01–40 Hz (−3 dB points). Electrode impedances were kept below 5 kΩ. Off-line data were segregated into 2048 msec epochs onsetting 102 msec prestimulus. The epoched data were downsampled to a 125-Hz sampling rate and algebraically re-referenced to linked mastoids. Trials containing movement artifact, horizontal or vertical EOG artifact other than blinks, or excessive baseline drift were rejected. The averaged ERPs were smoothed with a 5- point moving-window filter at a cutoff of 19.4 Hz (−3 dB). A previously described linear regression method (Henson, Rylands, Ross, Vuilleumeir, & Rugg, 2004) was used to correct blink artifacts for all subjects.

RESULTS

Neuropsychological Test Scores

The raw scores from the neuropsychological test battery are summarized in Table 1. Young subjects outperformed the older group on tests emphasizing processing speed, such as the Digit/Symbol Coding test and the Trail Making tests. As can be seen from the table, young subjects also tended to demonstrate higher scores on the tests of long-term memory, although these differences in performance did not reach statistical significance.

Behavioral Performance

Performance in the study and test phases of the ERP procedure was analyzed according to age group (young vs. older), study material (word vs. picture), and retrieval task (recognition vs. source). Analysis of variance (ANOVA) of the proportions of accurate decisions revealed no main effect of age. Performance in the study phases is summarized in Table 2. The main effect of study material was significant [$F(1, 30) = 25.75, p \leq .001$], with better performance in the picture than in the word condition. Significant Task × Material and Group × Task × Material interactions [$F(1, 30) = 9.55$, $p \leq .01$ and $F(1, 30) = 4.18$, $p \leq .05$, respectively] were elucidated with separate analyses conducted in each age group. The Task × Material interaction was significant in the older group [$F(1, 15) = 18.06$, $p \leq .001$], but not in the young group. This interaction in the older group reflected more accurate decisions on study pictures than study words in the recognition condition [$F(1, 15) = 16.11$, $p \leq .001$], but not in the source condition. ANOVA of response times revealed that study decisions were made more quickly in the picture conditions than in the word conditions [1109 msec vs. 1251 msec, respectively; $F(1, 30) = 16.65$, $p \leq .001$]. The effect of age was not significant, nor did it interact with any other factor.

Test performance for both the recognition and source tasks was analyzed in terms of item memory and response bias. Performance in the source task was also subjected to a separate analysis to focus on source accuracy. Because of their significance in relation to the primary ERP data, responses to new items were also subjected to separate analyses. Performance in the test phases is summarized in Table 3.

Item (recognition) memory was measured by the discrimination index Pr [P Hit − P False Alarm] (see Snodgrass & Corwin, 1988). ANOVA revealed main effects of age [$F(1, 30) = 8.61, p \leq .01$] and study material [$F(1, 30) = 5.77$, $p \leq .05$], with no interaction between these factors. These effects reflected lower item memory in older than young adults (0.65 vs. 0.74, respectively) and in the picture condition than in the word condition (0.67 vs. 0.72, respectively). Response bias was measured by the index Br [False Alarm rate/(1 − (Hit rate − False Alarm rate))], after correcting hit and false alarm rates according to the method proposed by Snodgrass and Corwin (1988). The main effect of retrieval task [$F(1, 30) = 10.63$, $p \leq .01$] indicated that there was a more conservative bias in the source tasks than in the recognition tasks (0.31 vs. 0.39, respectively). The Group × Material interaction was also significant [$F(1, 30) = 15.15$,

Table 2. Mean Accuracy and Response Time (Standard Deviations in Brackets) on the Study Phase of Each Retrieval Condition

	Young Adults				*Older Adults*			
	Recognition Task		*Source Task*		*Recognition Task*		*Source Task*	
	Word	*Picture*	*Word*	*Picture*	*Word*	*Picture*	*Word*	*Picture*
Response accuracy	0.87 (0.06)	0.93 (0.04)	0.88 (0.06)	0.92 (0.04)	0.84 (0.08)	0.92 (0.04)	0.88 (0.06)	0.89 (0.04)
Response time	1227 (311)	1017 (144)	1233 (282)	1056 (200)	1273 (271)	1146 (137)	1274 (161)	1218 (157)

$p \leq .001$]. Separate analyses in each age group revealed that older adults adopted a more conservative criterion in the word conditions than in the picture conditions [$F(1, 15) = 37.92$, $p \leq .001$], whereas young subjects adopted similar criteria (Table 2).

Source memory, as measured by the proportion of correctly recognized items for which source was accurately retrieved, was analyzed according to age group (young vs. older) and study material (word vs. picture). ANOVA revealed main effects of age [$F(1, 30) = 10.22$, $p \leq .01$] and study material [$F(1, 30) = 41.13$, $p \leq .001$]. These effects reflected a higher proportion of correct source judgments in young subjects than in older adults (0.76 vs. 0.64, respectively) and in the picture than in the word condition (0.76 vs. 0.64, respectively). The Age × Material interaction was not significant.

ANOVA of correct rejection rates revealed main effects of study material [$F(1, 30) = 7.37$, $p \leq .05$] and retrieval task [$F(1, 30) = 5.66$, $p \leq .05$], with more accurate responding in the word than in the picture condition and in the source than in the recognition tasks. The main effect of group was not reliable. However, the Group × Material interaction was significant [$F(1, 30) = 7.23$, $p \leq .05$]. Separate analyses in each age group revealed that the effect of study material was significant in the older group [$F(1, 15) = 25.16$, $p \leq .001$], but not in the young group (see Table 3). Importantly, there was no interaction between the factors of group or material with task. ANOVA of correct rejection response times revealed main effects of age [$F(1, 30) = 4.94$, $p \leq .05$], study material [$F(1, 30) = 106.89$, $p \leq .001$], and retrieval task [$F(1, 30) = 5.02$, $p \leq .05$], with no interactions between

Table 3. Mean Scores (and Standard Deviations in Brackets) on the Test Phases of the Memory Tasks

	Young Adults				*Older Adults*			
	Recognition Task		*Source Task*		*Recognition Task*		*Source Task*	
	Word	*Picture*	*Word*	*Picture*	*Word*	*Picture*	*Word*	*Picture*
Response Rates								
Correct rejections	0.89 (0.11)	0.88 (0.10)	0.92 (0.08)	0.93 (0.09)	0.91 (0.09)	0.84 (0.08)	0.92 (0.06)	0.86 (0.07)
Hits	0.88 (0.11)	0.83 (0.07)	0.85 (0.09)	0.78 (0.12)	0.78 (0.08)	0.78 (0.13)	0.73 (0.13)	0.79 (0.09)
Correct source as proportion of recognition hits			0.69 (0.15)	0.83 (0.11)			0.59 (0.09)	0.68 (0.12)
Correct source as proportion of all old items			0.58 (0.16)	0.63 (0.14)			0.43 (0.13)	0.54 (0.13)
Performance Indices								
Item recognition (Pr)	0.77 (0.16)	0.71 (0.14)	0.77 (0.10)	0.70 (0.18)	0.69 (0.12)	0.62 (0.13)	0.65 (0.13)	0.65 (0.06)
Response bias (Br)	0.46 (0.30)	0.39 (0.16)	0.36 (0.24)	0.23 (0.17)	0.29 (0.17)	0.44 (0.18)	0.26 (0.16)	0.40 (0.18)
Response Time								
Correct rejections	1043 (271)	1200 (280)	1059 (267)	1231 (284)	1188 (216)	1331 (237)	1235 (202)	1498 (253)
Hits	1007 (216)	1052 (204)	1130 (297)	1200 (279)	1154 (166)	1177 (187)	1307 (196)	1455 (215)
Source hits			717 (377)	639 (312)			966 (317)	884 (278)

these factors. The effects reflect longer response times in older than young adults (1313 msec vs. 1133 msec, respectively), in the picture than in the word condition (1315 msec vs. 1131 msec), and in the source than in the recognition tasks (1256 msec vs. 1191 msec).

In sum, the analyses of test performance revealed age-related reductions in item and source memory. In addition, both response criterion and correct rejection rate varied as a function of study material in the older group only. Importantly, neither of the Age × Material interactions was modified by the factor of task.

ERP Study Material Effects for New Items

The ERP correlates of differential retrieval cue processing were assessed by contrasting the ERPs elicited by correctly rejected (new) test items according to study material (words vs. pictures). Grand-average ERPs elicited by correct rejections as a function of study material and retrieval task are illustrated for the electrode sites employed in the data analyses (see below) in Figure 1 and are shown in greater detail for the Cz electrode site in Figure 2. Mean numbers of trials (range in parentheses) constituting each young subject's waveforms were 27 (19–38) for the recognition-word condition, 28 (19–36) for the recognition-picture condition, 28 (18–36) for the source-word condition, and 29 (19–39) for the source-picture condition. With respect to older subjects, the mean numbers of trials constituting the waveforms were 30 (16–38) for recognition words, 27 (19–35) for recognition pictures, 29 (22–38) for source words, and 27 (19–36) for source pictures. As can be seen in Figure 1, in both tasks, ERPs in the young subjects are more positive-going when elicited by new items in the word condition than the picture condition from around 300 to 1000 msec. Relative to the young group, study material effects in the ERPs of the older subjects appear to be delayed and attenuated in the recognition task, but to

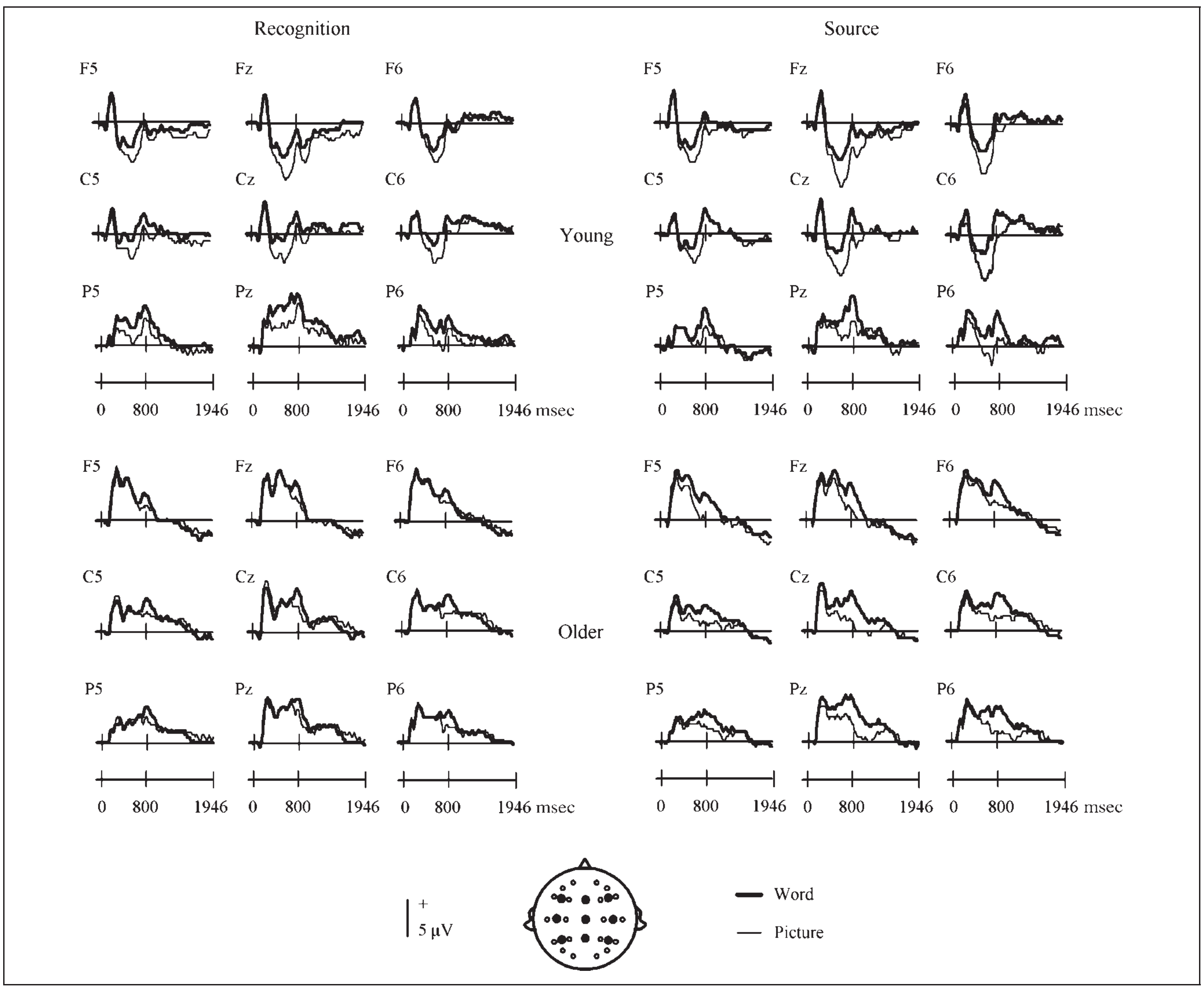


Figure 1. Grand-average ERP waveforms from the nine electrodes indicated, showing study material effects (word vs. picture conditions) in the recognition and source tasks for young and older adults.

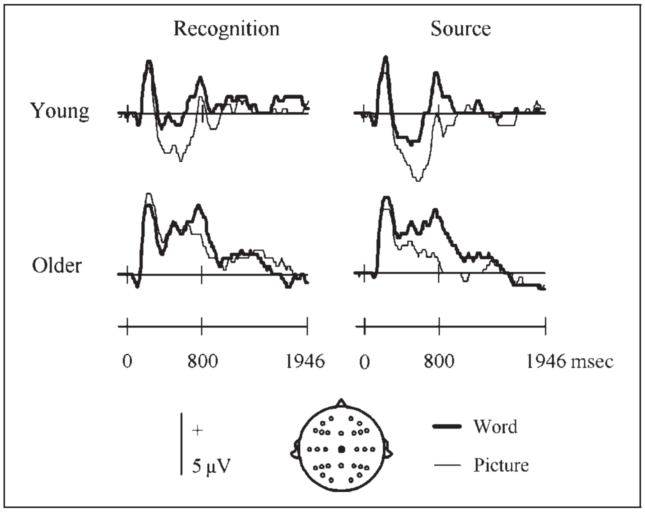


Figure 2. Grand-average ERP waveforms from the Cz electrode, showing study material effects in the recognition and source tasks for young and older adults.

have comparable onset latencies and magnitudes in the source task.

To address the hypothesis that the effects of age on differential cue processing are modulated by retrieval task (see Introduction), the first part of the analyses contrasted ERP study material effects as a function of age group and retrieval task. On the basis of visual inspection of the effects evident in Figure 1, ERPs were quantified by measuring the mean amplitude (with respect to the mean of the prestimulus baseline) of four latency regions: 200–300, 300–500, 500–800, and 800–1200 msec. The second and third of these regions correspond to the earliest two regions analyzed by Morcom and Rugg (2004). Analyses were conducted from the nine electrode sites illustrated in Figure 1. These sites are the same as those employed for the analysis of task demands on ERP new-item effects by Johnson and Rugg (2006b), and overlap with those employed by Morcom and Rugg. They were factored by longitudinal chain (left, midline, right) and anterior–posterior location (frontal, central, parietal). Global ANOVAs were performed on the data from each latency region by incorporating the additional factors of age group (young vs. older), retrieval task (recognition vs. source), and study material (word vs. picture). To elucidate the interactions involving the factor of group, subsidiary groupwise ANOVAs were conducted with the factors of retrieval task, study material, and the two electrode site factors. In addition, to determine whether the present findings for the recognition task replicated those of Morcom and Rugg, as well as to directly contrast effects in the source task, taskwise subsidiary ANOVAs were also conducted with the factors of age group, study material, and the two electrode site factors.

In a second set of analyses conducted on the new-item ERPs, we contrasted the scalp topographies of study material effects according to age. The effects were quantified as the differences in mean amplitude within the selected latency regions. The differences were rescaled by range normalization prior to analyses to remove the confounding effects of global amplitude differences between tasks or groups (McCarthy & Wood, 1985).

Magnitude Analysis of Study Material Effects for New Items

We comment below on those effects involving the effects of study material and their interactions with task and age group (see Table 4 for a summary of the relevant findings from the global ANOVAs and the follow-up groupwise and taskwise ANOVAs, and Figure 3 for a graphical depiction of the key findings). The global ANOVAs revealed significant Group × Material interactions in every latency region except in the 800–1200 msec region. More importantly, the factors of group, material, and task entered into significant interactions in the ANOVAs of the 200–300 and 300–500 msec regions. In the case of the 500–800 msec region, the interaction between group, material, task, and chain approached significance [$F(2, 59.5) = 2.74$, $p = .07$].

ANOVAs conducted separately on the data from the young subjects revealed reliable study material effects in all latency regions. An interaction involving the factors of task, material, and chain was significant in the 200–300 msec region. The interaction reflects a tendency toward larger material effects in the recognition task at left hemisphere electrodes. This finding was unpredicted and will not be discussed further.

In the older group, follow-up ANOVAs revealed interactions involving the factors of study material and task in every latency region. Further analyses revealed that, in the source task, the effects of study material and, in the 500–800 msec and 800–1200 latency regions, the interaction of this factor with chain and site, were reliable [$Fs(1, 15) = 4.80–17.23$]. By contrast, study material effects in the recognition task, whether in the form of a main effect or in interaction with other factors, were uniformly nonsignificant (max $F = 1.98$).

To directly compare the present results with those of Morcom and Rugg (2004), subsidiary ANOVAs were conducted on the data from the recognition task alone. As is evident in Table 4 and Figure 3, Group × Material interactions were significant in the 200–300, 300–500, and 500–800 msec latency regions, reflecting smaller study material effects in the older subjects. Group × Material × Chain interactions were also significant in the 200–300 and 300–500 msec latency regions. Further ANOVAs, broken down by chain, revealed that the Group × Material interaction was significant in the left and middle chains for the 200–300 msec latency region [$Fs(1, 30) = 5.62$ and 5.49, respectively for each chain, $ps \leq .05$], and in the middle and right chains for the 300–500 msec latency region [$Fs(1, 30) = 8.79$ and 9.74, respectively, $ps \leq .01$].

Table 4. Outcome of Global ANOVAs, and Subsidiary Group- and Taskwise ANOVAs, for Mean Amplitudes of New-item ERPs in Each of the Latency Regions Indicated

Latency Region (msec)	*Analysis*	*Effect*	*df*	*F*	*p*
200–300	Global	Material	1, 30	11.30	≤.01
		Group × Material	1, 30	5.26	≤.05
		Material × Task × Chain	2, 59.2	3.54	≤.05
		Group × Material × Task × Chain	2, 59.2	6.44	≤.01
	Young	Material	1, 15	14.25	≤.01
		Material × Task × Chain	2, 29.6	7.60	≤.01
	Older	Material × Task	1, 15	5.58	≤.05
	Recognition	Group × Material	1, 30	6.22	≤.05
		Group × Material × Chain	2, 60	4.74	≤.05
	Source	Material	1, 30	11.55	≤.01
		Material × Chain	1.5, 46.1	4.05	≤.05
300–500	Global	Material	1, 30	20.01	≤.001
		Group × Material	1, 30	8.24	≤.01
		Group × Material × Task	1, 30	4.84	≤.05
		Group × Material × Chain	2, 58.7	3.23	≤.05
		Group × Material × Task × Chain	1.6, 48.0	5.33	≤.05
	Young	Material	1, 15	24.77	≤.001
		Material × Chain	1.9, 28.6	4.40	≤.05
	Older	Material × Task	1, 15	4.82	≤.05
	Recognition	Material	1, 30	7.11	≤.05
		Group × Material	1, 30	14.98	≤.001
		Group × Material × Chain	1.8, 53.1	3.89	≤.05
	Source	Material	1, 30	12.34	≤.001
		Group × Material × Chain	1.9, 55.7	4.79	≤.05
500–800	Global	Material	1, 30	67.72	≤.001
		Group × Material	1, 30	7.65	≤.01
		Material × Chain	1.9, 55.7	3.88	≤.05
		Material × Chain × Site	2.6, 77.2	5.40	≤.01
	Young	Material	1, 15	99.66	≤.001
		Material × Chain	2, 29.7	3.89	≤.05
	Older	Material	1, 15	10.71	≤.01
		Material × Task	1, 15	6.11	≤.05
		Material × Chain × Site	2, 30	5.72	≤.01
	Recognition	Material	1, 30	22.50	≤.001
		Group × Material	1, 30	6.87	≤.05
	Source	Material	1, 30	44.56	≤.001
		Material × Chain × Site	2.6, 76.6	5.85	≤.01
800–1200	Global	Material	1, 30	18.02	≤.001
	Young	Material	1, 15	8.54	≤.05
	Older	Material	1, 15	9.54	≤.01
		Material × Task	1, 15	5.96	≤.05
	Recognition	Material	1, 30	6.00	≤.05
	Source	Material	1, 30	14.59	≤.001

Only effects that involve the factor of material are reported.

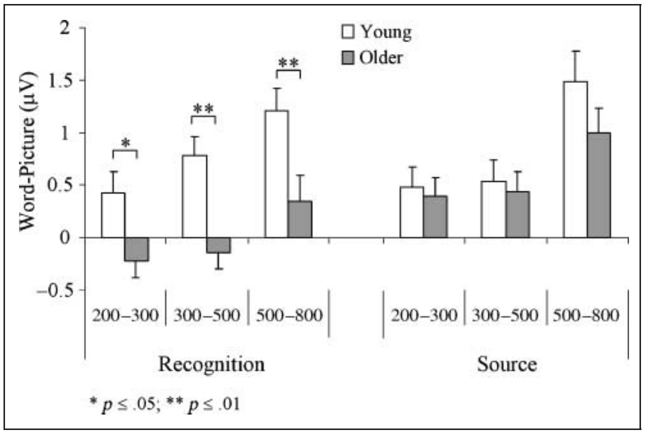


Figure 3. Mean amplitudes (and standard errors) of study material effects in young and older adults for the latency regions 200–300, 300–500, and 500–800 msec, averaged across the nine electrodes selected for analysis.

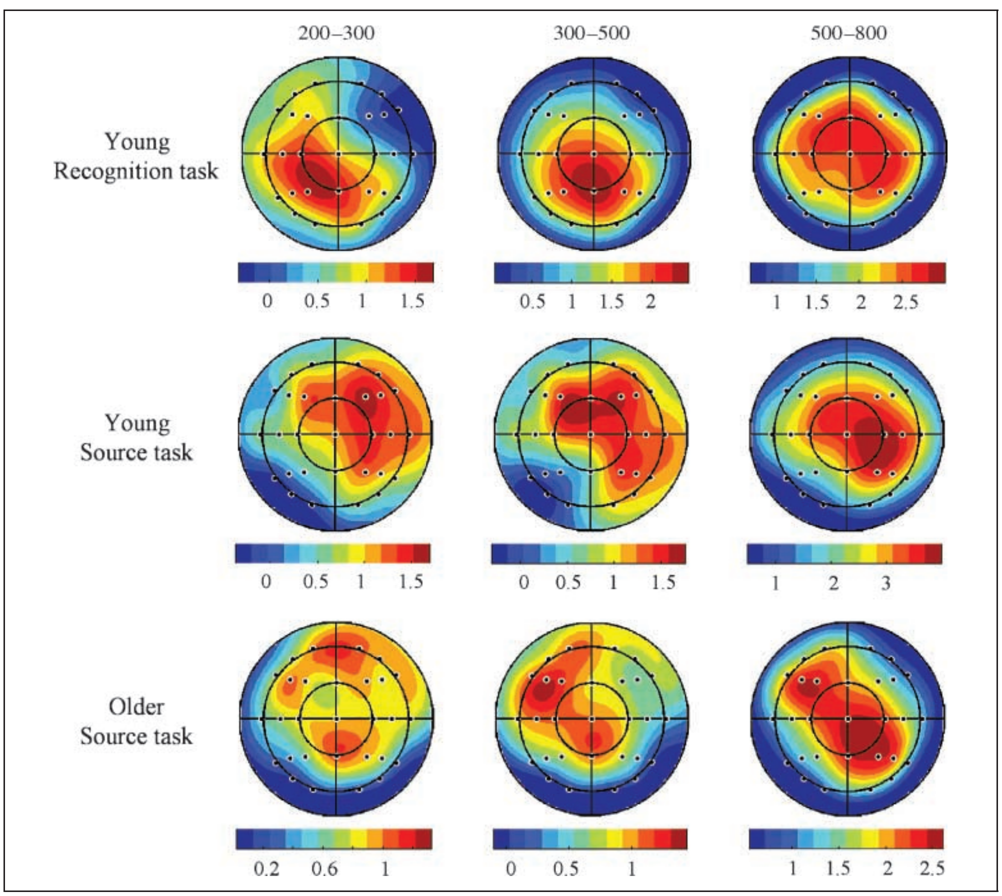
Analogous ANOVAs of the data from the source task revealed no effects involving the factors of group and material, other than in the 300–500 msec region, when a Group × Material × Chain interaction was evident. This interaction reflected a tendency for the study material effects to be right lateralized in the young subjects, but left lateralized in older adults (see below).

Topographic Analysis of Study Material Effects for New Items

Figure 4 illustrates the scalp distributions of study material effects in the source memory task for the latency regions—200–300, 300–500, and 500–800 msec—in which both age groups showed a reliable study material effect (the effect in the young group was not independently reliable in the source task in the 800–1200 msec latency range, hence, this region is omitted here). For illustrative purposes, the topographies of the study material effects in the young subjects for the recognition task are also presented (the older subjects failed to demonstrate reliable effects in this task for any region). To ensure adequate spatial sampling, topographic analyses were conducted on data from 21 electrodes (F7, T7, P7, F5, C5, P5, F3, C3, P3, Fz, Cz, Pz, F4, C4, P4, F6, C6, P6, F8, T8, P8). These were factored into seven chains (from left to right inferior, middle, superior, and midline chains) and three anterior–posterior locations (frontal, central, parietal). ANOVAs were conducted on the data from each latency region by incorporating the additional factor of age group (young vs. older).

ANOVA of the scalp topographies for the 200–300 msec latency region did not give rise to any significant effects involving the factor of group. In the 300–500 msec latency region, however, the Group × Chain interaction was

Figure 4. Topographic maps of study material effects for young adults in the recognition task and source task, and for older adults in the source task in the latency regions 200–300, 300–500, and 500–800 msec. Maps are normalized with respect to maxima and minima within each latency region.



significant [$F(2.3, 68.4) = 3.26$, $p \leq .05$]. Subsidiary ANOVAs revealed that whereas study material effects in the young subjects were right lateralized in this latency region [$F(2.7, 39.9) = 3.77$, $p \leq .05$], the effects were distributed bilaterally in the older group, as indicated by the failure to find any effects for the factors of chain, site, or their interaction. As in the 200–300 msec region, ANOVA of the data from the 500–800 msec latency region revealed no effects involving group.

In summary, the findings from the recognition task replicated those reported by Morcom and Rugg (2004) in demonstrating an age-related attenuation in the ERP correlates of differential cue processing. Crucially, there was no influence of age in the source task, with the two groups demonstrating ERP effects that were equivalent in both onset latency and magnitude. Age-related differences in the scalp distribution of study material effects were not reliable, except in the 300–500 msec latency region, where there was a modest difference between the groups in lateralization of the effects.

ERP Old/New Effects

There were sufficient trial numbers ($n \geq 15$) to form ERPs for the four different classes of hits from 15 young and 11 older subjects. Limitations on trial numbers meant that, in the source memory task, it was not possible to segregate recognized items on the basis of the accuracy of the subsequent source judgment. Because there was no evidence from the ANOVAs described in the following section that the magnitude of the old/new effects in either group interacted with the factor of task, ERPs elicited by old and new items were collapsed over this factor for illustrative purposes. Figure 5 shows the grand-average waveforms elicited by old and new items in each group from lateral frontal and parietal electrode sites. In the young group, the effects are most prominent over the left parietal scalp between around 400 and 1200 msec, and from right frontal electrodes thereafter. The left parietal effects in the older group appear to be markedly smaller and demonstrate a more symmetric scalp distribution than those of the young subjects. The later-onsetting right frontal effects, however, appear more comparable in magnitude between the groups.

Old/new effects were quantified by measuring the mean amplitude of two latency regions, 500–800 msec and 1600–1900 msec. The first region was employed to capture the relatively early-onsetting parietal old/new effect, whereas the second region quantified the seemingly right lateralized, temporally sustained frontal effect. In each case, data from the same nine electrode sites employed for the new-item analyses described above were subjected to ANOVA with factors of group,

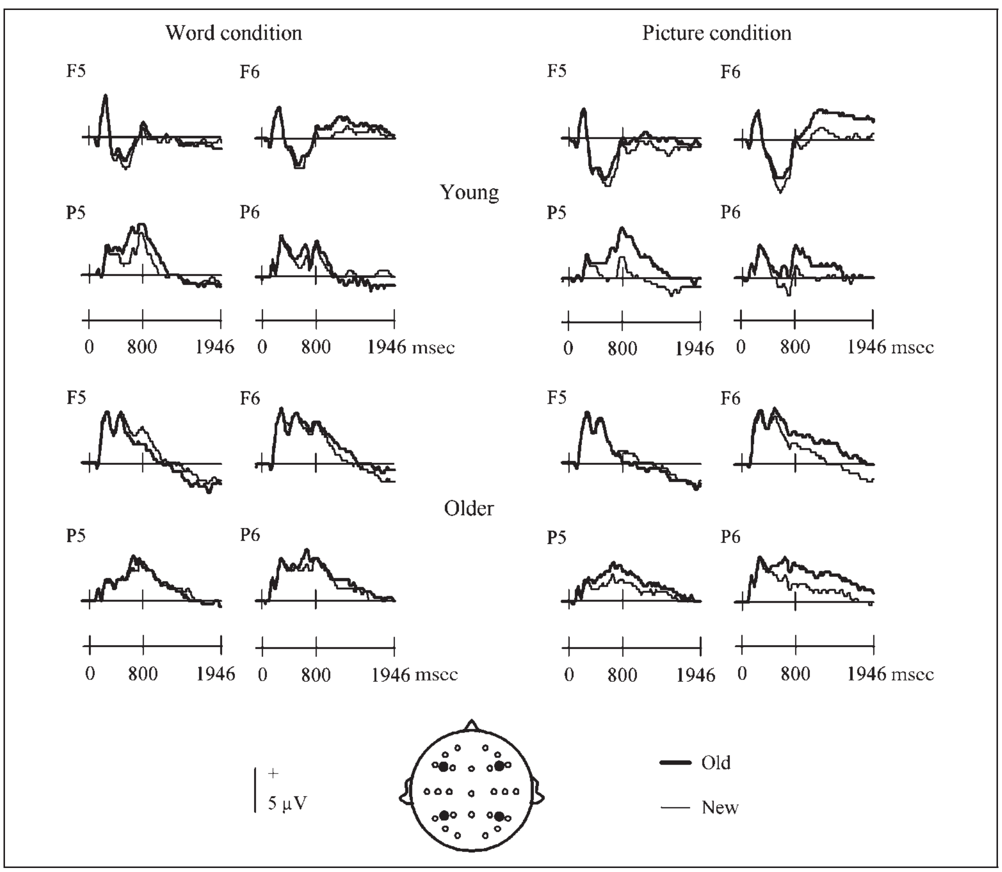


Figure 5. Grand-average ERP waveforms from lateral frontal and parietal electrodes, illustrating old/new effects in the word and picture conditions (collapsed across retrieval tasks) for young and older adults.

task, material, and electrode chain and site. Because these analyses are targeted specifically at elucidation of old/new effects in the two groups, only those ANOVA results including the old/new factor are described below. Subsidiary ANOVAs were performed as necessary to elucidate the results.

Magnitude Analysis of Old/New Effects

ANOVA of the data from the 500–800 msec latency interval revealed a significant old/new effect [$F(1, 24) = 20.88$, $p \leq .001$], which was modified by interactions with material [$F(1, 24) = 7.08$, $p \leq .05$], site [$F(1.2, 27.8) = 11.32$, $p \leq .01$], Chain × Site [$F(2.7, 65.5) = 6.92$, $p \leq .001$], and Group × Chain [$F(1.7, 41.8) = 6.32$, $p \leq .01$]. As is evident in Figure 5, the interaction with study material reflected larger old/new effects when pictures rather than words were studied. Separate groupwise ANOVAs revealed that old/new effects were reliable in both age groups [young adults: $F(1, 14) = 16.38$, $p \leq .001$; older adults: $F(1, 10) = 8.45$, $p \leq .05$]. Separate across-group ANOVAs conducted on the electrode chains over the left and right hemispheres revealed, for the left hemisphere, a significant old/new effect [$F(1, 24) = 14.03$, $p \leq .001$] that was modified by Group × Old/New interaction [$F(1, 24) = 11.53$, $p \leq .01$]. By contrast, ANOVA of the data from the right hemisphere gave rise solely to a main effect of old/new [$F(1, 24) = 12.91$, $p \leq .001$]. Further groupwise ANOVAs for the data from left hemisphere sites revealed a significant old/new main effect only in the young group [$F(1, 14) = 27.69$, $p \leq .001$], and significant Old/New × Site interactions in both groups [$F(1.3, 17.6) = 11.82$ and $F(1.4, 14.1) = 12.14$, $ps \leq .01$ in young and old groups, respectively]. The interaction reflects a trend for old/new effects to be of greater magnitude over the parietal scalp. Thus, old/new effects in both groups were reliable over both hemispheres, but were smaller in the older group than in the young over the left hemisphere.

A somewhat different pattern of effects was obtained for the 1600–1900 msec region. The main effect of old/new was not significant, and the old/new factor did not interact significantly with group, either singly or in concert with other factors. There were, however, reliable interactions between old/new and material [$F(1, 24) = 14.21$, $p \leq .001$], chain [$F(1.4, 34) = 10.00$, $p \leq .001$], site [$F(1.8, 43.9) = 3.80$, $p \leq .05$], Chain × Site [$F(2, 48.7) = 3.62$, $p \leq .05$], and Material × Chain × Site [$F(2.1, 50.1) = 4.64$, $p \leq .05$]. These interactions reflect the right anterior maximum of the effect in this latency range, and the tendency for the effect to be larger when pictures rather than words were the studied material. Separate ANOVAs of the data for each group revealed, in the young group, a significant interaction between old/new, material, chain, and site [$F(1.7, 23.8) = 3.99$, $p \leq .05$] and, in the older group, a significant interaction between old/new and chain [$F(1.3, 13) = 9.39$, $p \leq .01$].

Topographic Analysis of Old/New Effects

Figure 6 illustrates the scalp topographies in the 500–800 msec and 1600–1900 msec latency regions of the old/new effects from each group, collapsed across study material and task. The topographies were analyzed using the same 21 electrode sites that were employed for the analyses of the new-item effects, again factored by later chain and anterior–posterior site. Also as previously, the magnitudes of the old/new effects were range-normalized within group, material, and task prior to analysis.

ANOVA of the data from 500–800 msec latency region gave rise to a significant effect of site [$F(1.2, 29.4) = 20.97$, $p \leq .001$] and a Chain × Site interaction [$F(3.6, 87.4) = 6.58$, $p \leq .001$]. More importantly, there was also a significant interaction between group and chain [$F(1.9, 45.9) = 6.21$, $p \leq .01$]. As is evident from Figure 6, this result appears to reflect the differential lateralization of the effects in the two groups (left lateralized in the young, and right lateralized in the older subjects). This impression was confirmed by groupwise ANOVAs contrasting the data from the two hemispheres. These revealed a significant Hemisphere × Chain × Site interaction in the young group [$F(2.9, 40.1) = 5.36$, $p \leq .01$], and a significant Hemisphere × Site interaction for the older subjects [$F(2.0, 19.5) = 7.46$, $p \leq .01$]. The first of these interactions reflects the tendency for old/new effects in the young to be most strongly left lateralized over the posterior parietal scalp. The second finding is a

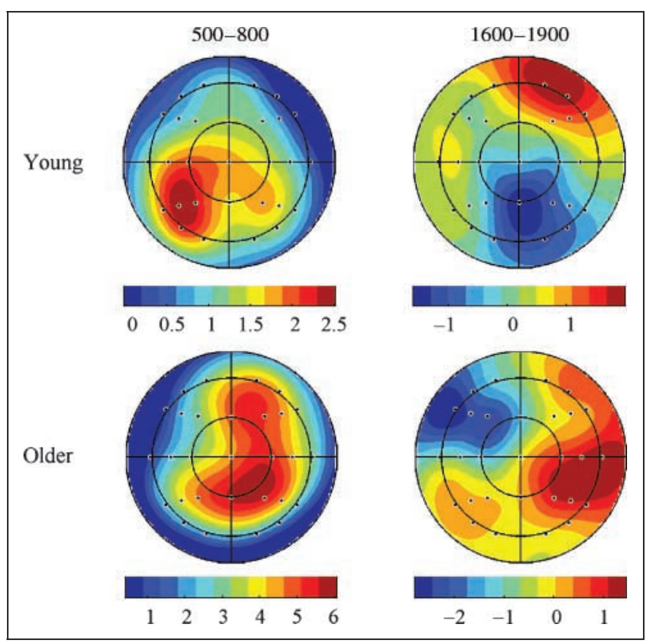


Figure 6. Topographic maps of old/new effects for young and older adults in the 500–800 and 1600–1900 msec latency regions (collapsed across study materials and retrieval tasks). Maps are normalized with respect to maxima and minima within each latency region.

consequence of stronger lateralization of old/new effects over central and frontal sites than over parietal sites in the older group.

ANOVA of the old/new topographies in 1600–1900 msec latency region gave rise to no effects involving the group factor, but to significant effects for chain [$F(1.6, 38) = 9.45$, $p \leq .001$], site [$F(1.7, 41.2) = 10.34$, $p \leq .001$], Chain × Site interaction [$F(2.8, 67.6) = 3.64$, $p \leq .05$], and Material × Chain × Site interaction [$F(5.1, 123.2) = 2.29$, $p \leq .05$]. As is evident from Figure 6, the first two of these findings reflect the right hemisphere maximum of the old/new effects in this latency range. The three-way interaction involving the factor of material reflects a tendency for these frontal effects to be more strongly lateralized when pictures rather than words were the studied material (data not shown).

In summary, old/new effects were reliable in both age groups in the 500–800 msec latency region. Age-related differences in the amplitude of these effects were confined to the left hemisphere. Indeed, old/new effects were left lateralized in the young subjects but were bilaterally distributed in the older group. By contrast, old/new effects for the 1600–1900 msec latency region were similar in amplitude and scalp distribution across age groups.

DISCUSSION

The aim of the present study was to investigate whether age-related attenuation of the ERP correlates of differential retrieval cue processing (also known as ERP ''retrieval orientation effects'') is sensitive to retrieval demands. Replicating prior findings (Morcom & Rugg, 2004), these effects were greater in magnitude in the young than in the older group when memory was assessed with a recognition memory test. Strikingly, the onset latencies and magnitudes of the ERP effects in the two groups were almost indistinguishable when the retrieval test required a source memory judgment. Below, we discuss the implications of these and other findings for the understanding of age-related differences in retrieval processing.

Behavioral Findings

The neuropsychological test scores revealed the typical pattern of age-related sparing and impairment of cognitive functions, with the exception of long-term memory performance. Although there was a trend for better memory in the young subjects in each test, in no case were the differences in test scores statistically significant. These findings are at variance with the pattern observed in prior studies using similar test batteries, including a recent study from our own laboratory that employed subjects from the same young and older populations that were sampled here (Duverne et al., 2007). Comparison of test performance between the present study and that previous study indicates that although the scores for older subjects are very similar, the scores for the young subjects are somewhat lower in the present case. We have no explanation for why the present sample of younger subjects seemingly underperformed on the long-term memory tests. It should be noted, however, that performance on the experimental tasks demonstrated a marked age-related memory impairment (see below).

Performance on the study phases was broadly comparable between the groups, with only a nonsignificant trend for slower responding in the older subjects. In both groups, study performance tended to be more accurate for pictures than for words, although this effect was absent in the older subjects for the source task. The explanation for this age-specific Material × Task interaction is unclear. Presumably, it reflects a shift in the encoding strategy adopted by older subjects in light of the different demands of the two tasks (subjects had prior practice with each study–test combination, and were informed of the nature of each upcoming test prior to the study phase). This finding serves as a caveat to our conclusion below that the task manipulation modulated the older subjects' ERP retrieval orientation effects by influencing retrieval strategy. Although a small effect, the Material × Task interaction evident for the older subjects' study accuracy might indicate that the ERP findings also reflect task-related differences in the nature of the encoded memory representations.

In both retrieval tasks, item memory demonstrated significant and additive effects of material and age, with older subjects performing at lower levels than the young group. As in several previous studies employing similar tasks (e.g., Johnson & Rugg, 2006a, 2006b; Robb & Rugg, 2002), performance was higher in the word than in the picture conditions. Source accuracy also demonstrated additive age and study material effects. In this case, however, although performance remained lower for the older subjects, it was the picture condition that was associated with the greater accuracy. The reason for this ''reversed'' study material effect is unclear. On the one hand, it may reflect the fact that, although less accessible (due to the incompatibility of study items and test cues), the episodic representations formed in response to the pictures were richer and more detailed than those for words. Thus, when these representations were successfully retrieved, they were more likely to support accurate source judgments than were word-based representations. Alternatively, the finding may reflect an additional benefit to item memory for words arising from the greater familiarity that is sometimes engendered when study and test items are perceptually similar rather than dissimilar (see Yonelinas, 2002, for a review). Regardless of the correct explanation, study material effects did not interact with age or task in the case of either item or source memory. Thus, these effects cannot account for the influence of age and task on ERP measures of differential cue processing.

Response bias varied with retrieval task, with both groups adopting more conservative response criteria in the source task. In addition, older subjects adopted more conservative criteria when words, rather than pictures, were the studied material. Importantly, this effect did not interact with retrieval task. Thus, it cannot account for the effects of task on the new-item ERPs of the older subjects. The same argument applies with respect to the finding that correct rejection rates differed according to study material in older but not young subjects; again, this effect did not interact with task.

ERP New-item Effects

The material-dependent differences in the ERPs elicited by new items in the young subjects closely resemble those described in previous studies employing similar experimental procedures (Hornberger et al., 2004, 2006; Johnson & Rugg, 2006a, 2006b; Herron & Rugg, 2003; Robb & Rugg, 2002). In the present study, these ERP effects were largely unaffected by the retrieval task manipulation, suggesting that the young subjects processed retrieval cues in a similar fashion in the two tasks (cf. Johnson & Rugg, 2006b). By contrast, the findings from the older subjects suggest that the differing demands of the two retrieval tasks had a substantial influence on their cue processing strategies. Thus, the present findings both replicate and extend the results reported by Morcom and Rugg (2004). In particular, they provide strong evidence that the failure of older subjects to adjust cue processing in response to different retrieval goals (Jacoby, Shimizu, Velanova, et al., 2005; Morcom & Rugg, 2004) reflects the adoption of a modifiable strategy rather than an inherent limitation on flexibility of cue processing. Thus, these findings appear to parallel those from studies investigating memory encoding strategies in older adults (see Light, 1991; Hasher & Zacks, 1988 for reviews). The findings from these studies demonstrate that when encoding is intentional, older subjects are less likely than the young to engage in effortful, semantically elaborate encoding strategies, leading to relatively large age-related differences in memory performance. These performance differences are reduced, however, when subjects undertake incidental study tasks that encourage the engagement of effective encoding operations (e.g., Naveh-Benjamin, 2000; Perfect, Williams, & Anderton-Brown, 1995; Spencer & Raz, 1995).

As was noted in the Introduction, Morcom and Rugg (2004) proposed three possible accounts of their finding of attenuated ERP correlates of differential retrieval cue processing in older adults, namely, a failure to form distinctive memory representations for words versus pictures, a lack of cognitive flexibility (and a consequent inability to differentially process retrieval cues), and the failure to spontaneously adopt material- or goal-dependent retrieval strategies. Although we cannot entirely discount the possibility that task-dependent encoding strategies played a role (see previous section), the present findings are most consistent with the third of these alternative accounts. Following Morcom and Rugg, we propose that when memory judgments receive significant support from familiarity-driven recognition, older adults process retrieval cues in a relatively passive manner, and refrain from an effortful, cue-driven memory search. When the task demands it, however, the same subjects are as capable of adopting differential cue processing strategies as are young subjects. An important question for the future is whether it is possible to devise training procedures that lead to the restoration of differential cue processing in older subjects in retrieval tasks such as yes/no recognition. Such procedures may have a useful role to play in ameliorating the effects of aging on episodic memory (see also Jacoby, Shimizu, Velanova, et al., 2005).

Finally, it should be noted that although ERP correlates of differential retrieval cue processing in the source task were very similar in their time courses and magnitudes in the two age groups, there was some evidence of age-related differences in scalp topography. Although the topographies of the ERP effects were statistically equivalent in the 200–300 and 500–800 msec latency regions, the results of the topographic analyses revealed that the effects were differentially lateralized in the 300–500 msec region (right lateralized in the young, bilateral/left lateralized in the older group). Given the absence of any trend for corresponding effects in the preceding and subsequent latency regions, and its relatively modest statistical significance, the reliability of this topographical effect is open to question. It is conceivable, however, that it represents an additional example of the tendency for older subjects to demonstrate more bilateral patterns of task-related cortical activity than the young (Cabeza, 2002; Dolcos, Rice, & Cabeza, 2002).

Old/New Effects

ERPs in the young subjects demonstrated robust differences according to the study status of the eliciting item (old vs. new). In the 500–800 msec latency region, these effects were maximal over the left posterior scalp, closely resembling the ''left parietal old/new effect'' reported in numerous prior publications, and widely assumed to be a neural correlate of recollection-driven recognition memory (e.g., Rugg & Curran, 2007; Friedman & Johnson, 2000). Old/new effects remained present until the end of the recording epoch, shifting in their scalp distribution to a right anterior maximum. These so-called right frontal old/new effects have also been described in numerous prior reports, and are generally interpreted as a neural correlate of processes supporting the monitoring and evaluation of retrieved information (e.g., Wilding & Herron, 2006; Rugg, Otten, & Henson, 2002; Van Petten, Luka, Rubin, & Ryan, 2002). Replicating prior findings (Johnson & Rugg, 2006b; Herron & Rugg, 2003), the left parietal (and right frontal) old/new effects were larger when pictures rather than words were the studied material. This study material effect has been ascribed to the greater amount of episodic information associated with retrieval of memories for pictures compared with words.

ERP old/new effects could be analyzed from only a subset of the older subjects (11/16), signaling the need for caution in the interpretation of the findings. It is, nonetheless, noteworthy that the findings for the older group replicated those reported by Morcom and Rugg (2004) in three respects. First, left parietal effects were smaller in the older subjects. Second, whereas these effects were strongly left lateralized in the young subjects, they were more symmetric in the older group with, if anything, a tendency to be right lateralized (indeed, the effects were equivalent in magnitude in the two groups over the right posterior scalp). Third, both groups demonstrated robust right frontal old/new effects that were comparable in magnitude, although these effects appear to be more diffusely distributed in the older than in the young subjects (see Figure 6).

Although attenuated left parietal effects in older subjects have been reported previously (Gutchess et al., 2007; Morcom & Rugg, 2004), this is not invariably the case, especially when the effects are elicited by items attracting correct source memory judgments in high-performing subjects (Duarte et al., 2006; Wegesin et al., 2002; Trott et al., 1999; Mark & Rugg, 1998; see Friedman et al., 2007, for a review). Together with analogous fMRI findings (Duverne et al., 2007; Morcom et al., 2007), these ERP data offer little support for the proposal that neural activity associated with successful recollection invariably declines in magnitude with increasing age. The question therefore arises why parietal old/new effects were attenuated in the present sample of older adults. In the case of the recognition task, an obvious explanation is that the attenuated effects in the older group reflect a lower proportion of trials on which recognition was accompanied by recollection (see above). In the source task, two factors likely conspired together to give rise to attenuated old/new effects in the older subjects. First, low trial numbers mandated that the ERPs for old items be formed from trials collapsed across source accuracy. Therefore, ERPs were formed from a higher proportion of source correct trials in the young than in the older subjects. Because parietal old/new effects are larger when elicited by items associated with correct rather than incorrect source judgments (e.g., Senkfor & Van Petten, 1998; Wilding & Rugg, 1996), one reason for the age-related differences in the magnitude of parietal old/new effects is the differential mixing of trials associated with correct versus incorrect source judgments in the two groups. This effect would likely have been exacerbated by the greater proportion of source correct trials due to ''lucky guesses'' in older than in young subjects. As source accuracy declines, the ratio of correct source judgments based on veridical retrieval as opposed to guessing also declines (Mark & Rugg, 1998). In the present case, for example, whereas approximately 80% of correct source judgments for pictures were associated with source recollection in the young subjects, this was true for only about 53% of the older subjects' judgments. Thus, even if ERPs from the source task had been formed from correct trials only, the magnitude of the resulting parietal old/new effects would still be expected to be smaller in the older group.

Whereas old/new effects over the left parietal scalp were attenuated in older subjects in the 500–800 msec latency range, the corresponding effects over the right hemisphere did not significantly differ with age. One possibility is that this finding reflects bilateral recruitment of the generators of parietal old/new effect in older subjects, perhaps in compensation for a decline in the efficiency of processes lateralized to the left hemisphere in the young (Cabeza, 2002; Dolcos et al., 2002). Recent fMRI studies of episodic retrieval in older and young subjects offer no support for this proposal, however (Duverne et al., 2007; Morcom et al., 2007), and neither do prior ERP studies (e.g., Wegesin et al., 2002; Trott et al., 1999; Mark & Rugg, 1998). An alternative possibility is that the right posterior old/new effects are reflections of processes functionally distinct from those associated with the left parietal effects (reflecting, perhaps, the ''targetness'' or salience of the eliciting event; Herron, Quayle, & Rugg, 2003), and that these processes are relatively unaffected by age.

The finding of robust old/new effects over the right frontal scalp of older subjects replicates some previous findings (Li et al., 2004; Morcom & Rugg, 2004; Mark & Rugg, 1998), but is inconsistent with two other studies (Wegesin et al., 2002; Trott et al., 1999). To the extent that right frontal effects are, indeed, neural correlates of postretrieval monitoring and evaluation (Wilding & Herron, 2006; Rugg et al., 2002; Van Petten et al., 2002), the present and prior findings of intact effects in older adults suggests that these processes are not necessarily compromised by increasing age. The factors responsible for the age-related attenuation of right frontal effects reported by Wegesin et al. (2002) and Trott et al. (1999) are currently unclear (see Li et al., 2004, for further discussion).

Concluding Comments

The present results add to the evidence that recognition memory retrieval cues are less likely to be subjected to goal-directed, differential processing with increasing age (Jacoby, Shimizu, Velanova, et al., 2005; Morcom & Rugg, 2004). The data go beyond previous findings, however, by demonstrating that age-related differences in cue processing (at least as indexed by ERPs) are sensitive the demands of the retrieval task, and can be absent when performance requires recollection of episodic details from the study phase. Thus, the failure of older subjects to demonstrate differential cue processing when undertaking recognition memory tests reflects the adoption of a specific retrieval strategy, rather than an inability to flexibly process cues in light of different retrieval goals.

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Note

1. To avoid confounding the neural correlates of cue processing with the neural correlates of retrieval success, ERP study material effects are typically investigated by contrasting the activity elicited by unstudied items, in response to which little or no information is retrieved.

REFERENCES

Cabeza, R. (2002). Hemispheric asymmetry reduction in old adults: The Harold model. *Psychology and Aging, 17,* 85–100.

Craik, F. I. M. (1977). Age differences in human memory. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the psychology*. New York: Van Nostrand Reinhold.

Craik, F. I. M., & Jennings, J. M. (1992). Human memory. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (pp. 51–110). Hillsdale, NJ: Erlbaum.

Daselaar, S. M., Veltman, D. J., Rombouts, S. A., Raaijmakers, J. G., & Jonker, C. (2003). Neuroanatomical correlates of episodic encoding and retrieval in young and elderly subjects. *Brain, 126,* 43–56.

Dolcos, F., Rice, H. J., & Cabeza, R. (2002). Hemispheric asymmetry and aging: Right hemisphere decline or asymmetry reduction. *Neuroscience and Biobehavioral Reviews, 26,* 819–825.

Duarte, A., Ranganath, C., Trujillo, C., & Knight, R. T. (2006). Intact recollection memory in high-performing older adults: ERP and behavioral evidence. *Journal of Cognitive Neuroscience, 18,* 33–47.

Duverne, S., Habibi, A., & Rugg, M. D. (2007). Regional specificity of age effects on the neural correlates of episodic retrieval. *Neurobiology of Aging, doi:10.1016/j.neurobiolaging.2007.04.022*. Epub ahead of print.

Friedman, D., & Johnson, R., Jr. (2000). Event-related potential (ERP) studies of memory encoding and retrieval: A selective review. *Microscopy Research and Technique, 51,* 6–28.

Friedman, D., Nessler, D., & Johnson, R., Jr. (2007). Memory encoding and retrieval in the aging brain. *Clinical EEG and Neuroscience, 38,* 2–7.

Gutchess, A., Ieuji, Y., & Federmeier, K. D. (2007). Event-related potentials reveal age differences in the encoding and recognition of scenes. *Journal of Cognitive Neuroscience, 19,* 1089–1103.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 12, pp. 193–225). New York: Academic Press.

Henson, R. N., Rylands, A., Ross, E., Vuilleumeir, P., & Rugg, M. D. (2004). The effect of repetition lag on electrophysiological and haemodynamic correlates of visual object priming. *Neuroimage, 21,* 1674–1689.

Herron, J. E., Quayle, A. H., & Rugg, M. D. (2003). Probability effects on event-related potential correlates of recognition memory. *Brain Research, Cognitive Brain Research, 16,* 66–73.

Herron, J. E., & Rugg, M. D. (2003). Retrieval orientation and the control of recollection. *Journal of Cognitive Neuroscience, 15,* 843–854.

Hornberger, M., Morcom, A. M., & Rugg, M. D. (2004). Neural correlates of retrieval orientation: Effects of study–test similarity. *Journal of Cognitive Neuroscience, 16,* 1196–1210.

Hornberger, M., Rugg, M. D., & Henson, R. N. (2006). ERP correlates of retrieval orientation: Direct versus indirect memory tasks. *Brain Research, 1071,* 124–136.

Jacoby, L. L., Shimizu, Y., Daniels, K. A., & Rhodes, M. G. (2005). Modes of cognitive control in recognition and source memory: Depth of retrieval. *Psychonomic Bulletin & Review, 12,* 852–857.

Jacoby, L. L., Shimizu, Y., Velanova, K., & Rhodes, M. G. (2005). Age differences in depth of retrieval: Memory for foils. *Journal of Memory and Language, 52,* 493–504.

Johnson, J. D., & Rugg, M. D. (2006a). Electrophysiological correlates of retrieval processing: Effects of consistent versus inconsistent retrieval demands. *Journal of Cognitive Neuroscience, 18,* 1531–1544.

Johnson, J. D., & Rugg, M. D. (2006b). Modulation of the electrophysiological correlates of retrieval cue processing by the specificity of task demands. *Brain Research, 1071,* 153–164.

Kluger, A., Ferris, S. H., Golomb, J., Mittleman, M. S., & Reisberg, B. (1999). Neuropsychological prediction of decline to dementia in nondemented elderly. *Journal of Geriatric Psychiatry and Neurology, 12,* 168–179.

Li, J., Morcom, A. M., & Rugg, M. D. (2004). The effects of age on the neural correlates of successful episodic retrieval: An ERP study. *Cognitive, Affective, & Behavioral Neuroscience, 4,* 279–293.

Light, L. L. (1991). Memory and aging: Four hypotheses in search of data. *Annual Review of Psychology, 42,* 333–376.

Mark, R. E., & Rugg, M. D. (1998). Age effects on brain activity associated with episodic memory retrieval. An electrophysiological study. *Brain, 121,* 861–873.

McCarthy, G., & Wood, C. C. (1985). Scalp distribution of event-related potentials: An ambiguity associated with analysis of variance models. *Electroencephalography and Clinical Neurophysiology, 62,* 203–208.

Morcom, A. M., Li, J., & Rugg, M. D. (2007). Age effects on the neural correlates of episodic retrieval: Increased cortical recruitment with matched performance. *Cerebral Cortex, 17,* 2491–2506.

Morcom, A. M., & Rugg, M. D. (2004). Effects of age on retrieval cue processing as revealed by ERPs. *Neuropsychologia, 42,* 1525–1542.

Naveh-Benjamin, M. (2000). Adult age differences in memory performance: Tests of an associative deficit hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26,* 1170–1187.

Nilsson, L. G. (2003). Memory function in normal aging. *Acta Neurologia Scandinavia Supplementum, 179,* 7–13.

Norman, M. A., Evans, J. D., Miller, W. S., & Heaton, R. K. (2000). Demographically corrected norms for the California Verbal Learning Test. *Journal of Clinical and Experimental Neuropsychology, 22,* 90–94.

Park, D. C., & Gutchess, A. H. (2005). Long-term memory and aging: A cognitive neuroscience perspective. In R. Cabeza, L. Nyberg, & D. C. Park (Eds.), *Cognitive neuroscience of aging* (pp. 218–245). New York: Oxford University Press.

Perfect, T. J., Williams, R. B., & Anderton-Brown, C. (1995). Age differences in reported recollective experience are due to encoding effects, not response bias. *Memory, 3,* 169–186.

Robb, W. G. K., & Rugg, M. D. (2002). Electrophysiological dissociation of retrieval orientation and retrieval effort. *Psychonomic Bulletin & Review, 9,* 583–589.

Rugg, M. D. (2005). Retrieval processing in human memory: Electrophysiological and fMRI evidence. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences* (3rd ed.). Cambridge, MA: MIT Press.

Rugg, M. D., Allan, K., & Birch, C. S. (2000). Electrophysiological evidence for the modulation of retrieval orientation by depth of study processing. *Journal of Cognitive Neuroscience, 12,* 664–678.

Rugg, M. D., & Curran, T. (2007). Event-related potentials and recognition memory. *Trends in Cognitive Sciences, 11,* 251–257.

Rugg, M. D., Otten, L. J., & Henson, R. N. (2002). The neural basis of episodic memory: Evidence from functional neuroimaging. *Philosophical Transactions of the Royal Society of London, Series B, 357,* 1097–1110.

Rugg, M. D., & Wilding, E. L. (2000). Retrieval processing and episodic memory. *Trends in Cognitive Sciences, 4,* 108–115.

Senkfor, A. J., & Van Petten, C. (1998). Who said what? An event-related potential investigation of source and item memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24,* 1005–1025.

Shimizu, Y., & Jacoby, L. L. (2005). Similarity-guided depth of retrieval: Constraining at the front end. *Canadian Journal of Experimental Psychology, 59,* 17–21.

Snodgrass, J. G., & Corwin, J. (1988). Pragmatics of measuring recognition memory: Applications to dementia and amnesia. *Journal of Experimental Psychology: General, 117,* 34–50.

Spencer, W. D., & Raz, N. (1995). Differential effects of aging on memory for content and context: A meta-analysis. *Psychology and Aging, 10,* 527–539.

Swick, D., Senkfor, A. J., & Van Petten, C. (2006). Source memory retrieval is affected by aging and prefrontal lesions: Behavioral and ERP evidence. *Brain Research, 1107,* 161–176.

Trott, C. T., Friedman, D., Ritter, W., Fabiani, M., & Snodgrass, J. G. (1999). Episodic priming and memory for temporal source: Event-related potentials reveal age-related differences in prefrontal functioning. *Psychology and Aging, 14,* 390–413.

Van Petten, C., Luka, B. J., Rubin, S. R., & Ryan, J. P. (2002). Frontal brain activity predicts individual performance in an associative memory exclusion test. *Cerebral Cortex, 12,* 1180–1192.

Velanova, K., Lustig, C., Jacoby, L. L., & Buckner, R. L. (2007). Evidence for frontally mediated controlled processing differences in older adults. *Cerebral Cortex, 17,* 1033–1046.

Wegesin, D. J., Friedman, D., Varughese, N., & Stern, Y. (2002). Age-related changes in source memory retrieval: An ERP replication and extension. *Brain Research, Cognitive Brain Research, 13,* 323–338.

Wilding, E. L., & Herron, J. E. (2006). Electrophysiological measures of episodic memory control and memory retrieval. *Clinical EEG and Neuroscience, 37,* 315–321.

Wilding, E. L., & Rugg, M. D. (1996). An event-related potential study of recognition memory with and without retrieval of source. *Neuropsychologia, 37,* 441–454.

Woodruff, C. C., Uncapher, M. R., & Rugg, M. D. (2006). Neural correlates of differential retrieval orientation: Sustained and item-related components. *Neuropsychologia, 44,* 3000–3010.

Yonelinas, A. P. (2002). The nature of recollection and familiarity: A review of 30 years of research. *Journal of Memory and Language, 46,* 441–517.