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Aging memory for pictures: Using high-density event-related potentials to understand the effect of aging on the picture superiority effect

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Abstract

High-density event-related potentials (ERPs) were used to understand the effect of aging on the neural correlates of the picture superiority effect. Pictures and words were systematically varied at study and test while ERPs were recorded at retrieval. Here, the results of the word–word and picture–picture study-test conditions are presented. Behavioral results showed that older adults demonstrated the picture superiority effect to a greater extent than younger adults. The ERP data helped to explain these findings. The early frontal effect, parietal effect, and late frontal effect were all indistinguishable between older and younger adults for pictures. In contrast, for words, the early frontal and parietal effects were significantly diminished for the older adults compared to the younger adults. These two old/new effects have been linked to familiarity and recollection, respectively, and the authors speculate that these processes are impaired for word-based memory in the course of healthy aging. The findings of this study suggest that pictures allow older adults to compensate for their impaired memorial processes, and may allow these memorial components to function more effectively in older adults.

Keywords: Aging; Recognition memory; Picture superiority effect; Event-related potentials; Dual process

1. Introduction

For more than 30 years the picture superiority effect has demonstrated that subjects are more likely to remember items if they are presented as pictures versus words (Shepard, 1976; see Mintzer & Snodgrass, 1999, for review). Recent research has focused on understanding the memorial processes that underlie this picture superiority effect (Ally & Budson, 2007; Langley et al., 2008). Investigations into episodic memory from a dual-process perspective have provided fairly convincing evidence that familiarity and recollection provide independent bases of the recognition of studied items (Woodruff, Hayama, & Rugg, 2006; Yonelinas, 2002). Familiarity has been described as an acontextual sense that a test item has been seen before, whereas recollection has been described as the retrieval of contextual information about a studied item at test (Woodruff et al., 2006). Using high-density event-related potentials (ERPs), Ally and Budson (2007) suggested that pictures enhanced recollection compared to words, serving as the neural basis of the picture superiority effect in young adults. Older adults also demonstrate the picture superiority effect (Park, Puglisi, & Sovacool, 1983; Winograd, Smith, & Simon, 1982). However, many studies have suggested that recollection is impaired in the course of healthy aging (Craik & Jennings, 1992; Light, 1991). The primary goal of the current study was to investigate the effect of aging on the

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neural correlates of the picture superiority effect. We hoped to determine whether the increased memory for pictures in older adults was due to enhanced recollection of studied items, or whether it was attributable to enhancement of other memorial processes, such as familiarity or post-retrieval verification and monitoring.

Although it is widely acknowledged that aging has an adverse effect on episodic memory (Balota, Dolan, & Duchek, 2000; Craik & Jennings, 1992; Light, 1991; Smith, 1996), exactly how aging affects the processes of recognition memory has been the subject of some debate. Researchers have demonstrated that recollection remains intact in some groups of healthy older adults (Cabeza, Anderson, Locantore, & McIntosh, 2002; Davidson & Glisky, 2002; Duarte, Ranganath, Trujillo, & Knight, 2006). However, the majority of studies report that recollection is generally impaired with age, while familiarity is spared (Daselaar, Fleck, Dobbins, Madden, & Cabeza, 2006; Howard, Bessette-Symons, Zhang, & Hoyer, 2006; Jacoby, 1999; Jennings & Jacoby, 1993; Jennings & Jacoby, 1997; Rybash & Hoyer, 1996; Spencer & Raz, 1995; Titov & Knight, 1997; Yonelinas, 2001; but see Light, Prull, La Voie, & Healy, 1999).

Recent studies have used different methodologies to better understand familiarity in the context of aging (Duarte et al., 2006; Toth & Parks, 2006). The majority of the tasks used in the laboratory to estimate familiarity rely on the ability to effectively report a confidence judgment or one's subjective feeling of familiarity. It has been suggested, however, that perhaps older adults are impaired in their ability to access or report on the phenomenological experience of familiarity (Prull, Dawes, Martin, Rosenberg, & Light, 2006). Yet familiarity is generally thought to be an automatic/obligate process, which likely occurs physiologically with or without one being able to report on the phenomenological experience of familiarity (Ally & Budson, 2007; Ecker, Zimmer, Groh-Bordin, & Meckinger, 2007; Toth, 1996; Yonelinas, 2002; Yonelinas & Jacoby, 1996). In other words, the neural correlate of familiarity is likely to occur in older adults even if they are impaired in their ability to report the subjective feeling of familiarity. The use of a physiologic measure of familiarity might eliminate the need to use subjective reports.

Due to their excellent temporal resolution, ERPs have recently been used to dissociate the processes of familiarity and recollection with a variety of different stimuli and experimental manipulations (Ally & Budson, 2007; Duarte et al., 2006; Li, Morcom, & Rugg, 2004; Woodruff et al., 2006). In addition to helping us understand when specific cognitive processes may occur with precise time sensitivity, ERPs can help to elucidate the duration and interaction of these cognitive processes. The literature reports that ERPs elicited by correctly classified old items (studied) are more positive in nature than ERPs elicited by correctly classified new items (unstudied) (Friedman & Johnson, 2000). This ERP phenomenon is referred to as the "old/new effect." Researchers suggest that a neural correlate of familiarity is an enhanced old/new effect peaking around 400 ms at bilateral frontal electrode sites, that appears to precede controlled attempts by the individual to recollect information (Curran, 2000; Friedman & Johnson, 2000; Rugg et al., 1998). Some researchers have referred to this component as the "N400" or "FN400;" we will refer to this component as the early frontal effect. Previous research has shown that more familiar unstudied test items elicited a larger early frontal effect than unfamiliar unstudied items (Curran, 2000; Goldmann et al., 2003). Further, Duzel, Yonelinas, Mangun, Heinze, and Tulving (1997) asked subjects to make either a "remember" judgment if they remembered specific details of an item's presentation at study, or a "know" judgment if they simply had a feeling of "knowing" that an item was shown at study but could not recollect details of the item's presentation. They found that responses associated with "know" judgments elicited a greater early frontal effect than "remember" judgments. Furthermore, a recent ERP study using confidence ratings suggested that the magnitude of the early frontal effect varied directly with familiarity strength (Woodruff et al., 2006).

Numerous studies have investigated the neural correlate of recollection. The literature describes this correlate as an enhanced old/new effect occurring maximally at left parietal regions between 500 and 800 ms after test stimulus onset. Researchers have often referred to this component as the "LPC;" we will refer to this component as the parietal effect. This effect is greater for items correctly identified as previously studied and is relatively insensitive to alterations in familiarity (Woodruff et al., 2006). Further, Duzel et al. (1997) found that the parietal effect was enhanced by responses associated with "remember" judgments compared to "know" judgments. Some researchers have argued that the parietal effect indexes the amount of information retrieved (Fjell, Walhovd, & Reinvang, 2005; Vilberg, Moosavi, & Rugg, 2006). Although it remains unclear exactly what role the parietal cortex is playing in recognition memory, the parietal activity may reflect the reactivation of the stored memory representation or the actual matching of representations stored in memory with perceptual representations of the test items (Addis & McAndrews, 2006; Ally & Budson, 2007; Schnyer, Nicholls, & Verfaellie, 2005; Wagner, Shannon, Kahn, & Buckner, 2005).

When recollection is poor, difficult, or additional information is needed at retrieval, subjects must engage in post-retrieval processing. It has been suggested that post-retrieval monitoring and verification operates on the product of a retrieval attempt by holding information in working memory while it is evaluated for task relevance (Achim & Lepage, 2005). ERP studies suggest that a late right frontal old/new effect between 1000 and 1800 ms is associated with the ongoing evaluation and monitoring of the product of the retrieval attempt, particularly when the contents of memory are evaluated for specific features or details (Allan, Wilding, & Rugg, 1998; Rugg & Wilding, 2000; Wilding & Rugg, 1996). More recently, investigators have reported evidence of this late frontal effect despite unsuccessful recollection, and suggested that in addition to ongoing evaluation, this activity may reflect an executive search function of the frontal lobes directing subsequent retrieval attempts (Ally & Budson, 2007; Budson et al., 2005; Goldmann et al., 2003; Li et al., 2004).

Research focusing on ERPs and recognition memory in older adults has mainly focused on the parietal and late frontal effects. Most of these studies have reported an attenuation of the parietal

effect in older adults (Fjell et al., 2005; Joyce, Paller, McIsaac, & Kutas, 1998; Morcom & Rugg, 2004; Nielsen-Bohlman & Knight, 1995; Rugg, Mark, Gilchrist, & Roberts, 1997; Senkfor & Van Petten, 1998; Swick & Knight, 1997; but see Mark & Rugg, 1998; Trott, Friedman, Ritter, & Fabiani, 1997), consistent with behavioral reports of impaired recollection. There has been a long-standing suggestion that a decline in the attentional resources allocated at encoding (Park, Smith, Dudley, & Lafronza, 1989; Salthouse, 1994) may be responsible for memories with less supportive or contextual information than those of younger adults (Craik, Naveh-Benjamin, Ishaik, & Anderson, 2000; Li et al., 2004; Light, 1991). One explanation for diminished recollection, based on ERP findings in older adults, is that there is an age-related decrease in the quantity or quality of information retrieved (Fjell et al., 2005).

The majority of ERP studies have suggested that the late frontal effect associated with recognition memory is relatively unaffected by age when source information is not needed at test (Li et al., 2004; Mark & Rugg, 1998; Morcom & Rugg, 2004; Wolk et al., 2005). These findings are consistent with imaging studies investigating episodic memory in older adults (Cabeza et al., 2002; Madden et al., 1999). In fact, Cabeza et al. (2002) reported that older adults may actually engage bilateral frontal regions as opposed to the right hemispheric dominance observed in younger adults, presumably to compensate for impairment of other brain processes.

To our knowledge, only two studies have commented on the early frontal effect and familiarity in healthy older adults. Morcom and Rugg (2004) found no difference in ERP amplitude during the 300–500 ms time interval between older and younger adults, suggesting that familiarity is intact in older adults. However, using a remember/know paradigm to understand memory for grayscale pictures, Duarte et al. (2006) reported that older adults did not exhibit the neural activity associated with familiarity during a 100–500 ms post-stimulus interval that was observed in younger adults.

To achieve the overall goal of understanding the effect of aging on the picture superiority effect, we compared the behavioral performance and the electrical activity of the brain in healthy older adults to that of the younger adults from Ally and Budson (2007). Behaviorally, we expected that like younger adults, older adults would also demonstrate the picture superiority effect. For the ERP results, we expected that the early frontal effect would be similar for younger and older adults for both pictures and words, reflecting older adults' intact ability to use familiarity when making memorial judgments. We also expected that the late frontal effect would be similar in both groups or possibly enhanced for the older adult group, due to older adults' potential need for additional post-retrieval processing compared to younger adults. However, we predicted that the parietal effect would be significantly diminished for pictures and words for the older adults compared with the younger adults, reflecting the older adults' relatively impaired recollection. Finally, we hypothesized that the increased memory for pictures in older adults would be due to the ability of pictures to enhance the early and late frontal effects relative to words. This would reflect and increased ability of older adults to rely on familiarity and post-retrieval processing to compensate for impaired recollection of pictures compared to words.

2. Materials and methods

2.1. Design overview

The experimental design systematically varied words and pictures at study and test to generate four separate study-test conditions: word–word; picture–picture; word–picture; picture–word. All conditions presented 50 stimuli at study and 100 stimuli at test (50 old, 50 new). Older adults completed the four study-test conditions in two 1.5 h sessions over the course of 2 days, with breaks between each condition. High-density ERPs were recorded at test.

2.2. Subjects

Seventeen older adults (10 female) with a mean education of 16 years and an age range of 69–83 (mean 74.17) participated in the experiment. Subjects were excluded if they had a first-degree relative with a history of a memory disorder or Alzheimer's disease, if they had a significant history of cerebrovascular disease or another neurodegenerative disorder, or if they were currently being treating for a psychiatric disorder such as depression. All subjects were right-handed, English was their native language, and subjects were required to have corrected 20/30 or better color vision. The study was approved by the human studies committee of the Edith Nourse Rogers Memorial Veterans Hospital. All subjects gave IRB-approved informed consent before participating in the study, and were compensated at the rate of US$ 25 per hour. To understand the effect of aging on the picture superiority effect, the current study utilized the younger adults from Ally and Budson (2007). These seventeen younger adults (7 female) had a mean education of 14 years and ranged in age from 18 to 25 (mean 21.24).

The older adults completed a brief neuropsychological battery to confirm cognitive functioning in the average range. These tests were administered in a separate 45 min session. Subjects were first administered the Mini Mental State Examination (Folstein, Folstein, & McHugh, 1975), on which a minimum score of 27 was required for participation. Subjects were then administered the CERAD word list memory test (Morris et al., 1989), Trail Making Test Part B (Adjutant General's Office, 1944), Verbal Fluency (Monsch et al., 1992) and the 15-item Boston Naming Test (Mack, Freed, Williams, & Henderson, 1992). Mean scores (and standard deviations) for the older adult group on our neuropsychological battery were the following: MMSE = 29.33 (0.84); CERAD word list immediate recall over 3 trials/30 = 22 (3.12), delayed recall/10 = 7.25 (1.51), recognition/10 = 9.75 (0.41); trails B = 89.58 (33.39) seconds; word fluency to letters (F, A, S) = 47.65 (7.34); word fluency to categories (animals, fruits, vegetables) = 50.06 (11.73); 15 item Boston Naming Test = 14.53 (0.97).

2.3. Experimental material and methods

The color pictures used in the current study were the same stimuli set used by Ally and Budson (2007) and were obtained from a previous stimuli set used by Gallo, Kensinger, and Schacter (2006). The pool of experimental stimuli consisted of 480 color pictures of nameable objects (nouns) and 480 words corresponding to the names of the objects. From the total pool, 400 pictures were randomly selected. The 400 pictures were then piloted in a naming study involving 5 young adults prior to Ally and Budson (2007). Pictures with poor naming scores were replaced as needed. The final 400 items were counterbalanced across each of the four study-test conditions. The studied and unstudied items and condition order were also counterbalanced across subjects. Color pictures were presented in central vision on a white background, with an average height of 13 cm and an average width of 15 cm. Words were presented in central vision in black uppercase letters 4 cm in height, also on a white background. All stimuli were presented on a 21 in. flat screen computer monitor positioned 48 in. from the subject.

During the study portion of all conditions, subjects were asked to make like/dislike judgments of the stimuli, and asked to remember the stimuli for a subsequent memory test. Each trial began with a 1000 ms fixation character ("+") prior to the presentation of study stimuli. Study stimuli were then presented for

2000 ms followed by the question, "Do you like this item?" Subjects were then prompted to button press to signify their like/dislike judgment.

Each test trial began with a 1000 ms fixation character ("+") prior to the presentation of the stimuli. Test stimuli were presented for 1500 ms, followed by the question, "Is this item old or new?" Subjects were then prompted to button press to signify their old/new judgment. Subjects were asked to hold their old/new response until the question appeared immediately after stimuli presentation to minimize response-related ERP artifact during the commonly used 1800 ms epoch. We acknowledge that asking participants to keep their response "in mind," or alternatively, inhibiting their natural inclination to respond before the prompt may affect the electrophysiological data; particularly the late frontal effect. However, presumably because subjects would be engaging in this activity in all trials, this is less important in the old/new differences waves and topographies as this activity should be removed when subtracting correct rejections from hits.

2.4. ERP procedure

Subjects were seated in a hardback chair and fitted with an Active Two electrode cap (Behavioral Brain Sciences Center, Birmingham, UK). A full array of 128 Ag-AgCl BioSemi (Amsterdam, The Netherlands) "active" electrodes were connected to the cap in a pre-configured montage which places each electrode in equidistant concentric circles from 10 to 20 position Cz (Fig. 1). Active electrodes are amplified through the electrode at the source and do not require abrading of the skin or measuring skin-electrode impedance levels. In addition to the 128 scalp electrodes, two mini-biopotential electrodes were placed on each mastoid process. Finally, vertical and horizontal EOG activity was recorded from bipolar electrodes placed below the left eye and on the outer canthus of the left and right eye. EEG and EOG activity was amplified with a bandwidth of 0.03–35 Hz (3 dB points) and digitized at a sampling rate of 256 Hz. Recordings were referenced to a vertex reference point, but were later re-referenced to a common average reference to minimize the effects of reference-site activity and accurately estimate the scalp topography of the measured electrical fields (Curran, DeBuse, Woroch, & Hirshman, 2006; Dien, 1998).

The sampling epoch for each test trial lasted for a total of 2000 ms, which included a 200 ms pre-stimulus baseline period. This pre-stimulus period was used to baseline correct averaged ERP epochs lasting 1800 ms. ERPs were averaged and corrected using the EMSE Software Suite (Source Signal Imaging, San Diego, CA, USA). Trials were corrected for excessive EOG activity using the empirical EMSE Ocular Artifact Correction Tool, in which artifact data are manually identified from the clean data by the investigator. The Ocular Artifact Tool then produces a logarithmic ratio of artifact data versus clean data and subtracts artifact data from all channels where it is detected. Trials were discarded from the analyses if they contained baseline drift or movement greater than 90 μV. Individual bad channels were corrected with the EMSE spatial interpolation filter.

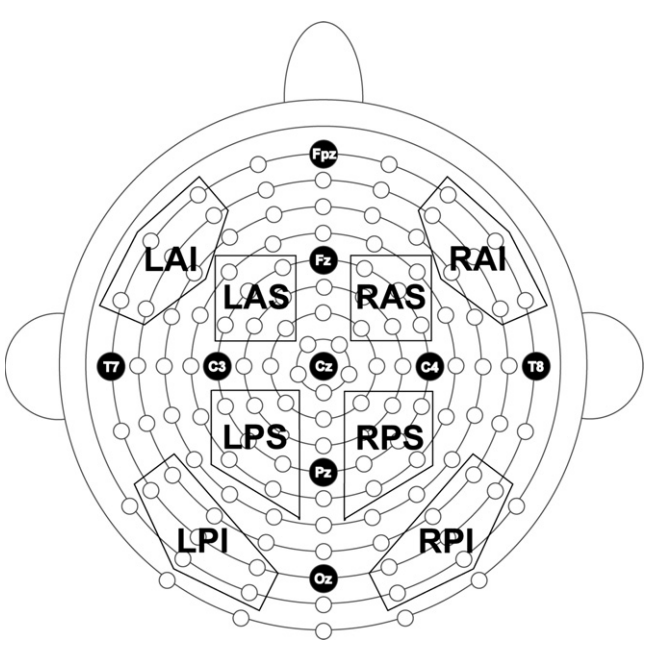

Fig. 1. Positions of the 128 electrodes on the bio-semi active two headcap with the eight regions of interest shown.

3. Results

Previous research has shown that when study and test modality are not matched, such as in the picture–word and word–picture conditions, the neural correlates of recognition memory are profoundly affected (Ally & Budson, 2007; Schloerscheidt & Rugg, 2004). These two conditions were not relevant to the current investigation, and therefore were not presented. To better understand the effect of aging on the neural correlates of the picture superiority effect, only the results of the word–word and picture–picture conditions were analyzed.

3.1. Behavioral performance

Recognition accuracy was calculated using the straightforward discrimination index Pr (%hits − %false alarms; Snodgrass & Corwin, 1988), and was used to compare the performance of the older adults in the current study to the performance of the younger adults in Ally and Budson (2007). A repeated measures ANOVA with the factors of group (old, young) and condition (word–word, picture–picture) was performed. Follow-up *t*-tests were performed as necessary. Results revealed no effect of group [$F(1, 16) < 1$], but an effect of condition [$F(1, 16) = 11.290$, $p = 0.002$], indicating that pictures were better remembered than words for both groups. There was also an interaction of group and condition [$F(1, 32) = 8.459$, $p = 0.007$], indicating that the magnitude of the picture superiority effect was greater for older adults than for younger adults. Follow-up *t*-tests revealed that there was a trend towards worse performance on the word–word condition for the older adults [$t(32) = 1.767$, $p = 0.089$], but no difference between groups in accuracy on the picture–picture condition [$t(32) < 1$]. Further analyses of the older adults data revealed that there was no difference in the false alarm rate between the word–word and picture–picture conditions [$t(16) < 1$], but that there was a significantly greater number of hits for the picture–picture condition [$t(16) = 4.459$, $p < 0.001$]. Table 1 shows the behavioral data for both groups.

Table 1
Behavioral performance using index Pr (%hits − %false alarms)

Condition	Accuracy (Pr)	
	Older adults	Younger adults
Word–word	0.81	0.86
Picture–picture	0.90	0.88
Word–picture	0.72	0.80
Picture–word	0.82	0.87

3.2. ERP results

ERP analysis was guided by previous research and began with ANOVAs performed on selected time intervals (300–500, 500–800, 1000–1800 ms). These time intervals have been previously associated with the three components of the old/new ERP effect (early frontal effect, parietal effect, late frontal effect, respectively) as described above (Budson et al., 2005; Curran et al., 2006; Curran, 2000, 2004). Mean amplitudes were calculated for these three time intervals, which were then averaged across groups of electrodes that formed eight separate regions of interest [left anterior inferior (LAI), right anterior inferior (RAI), left anterior superior (LAS), right anterior superior (RAS), left posterior superior (LPS), right posterior superior (RPS), left posterior inferior (LPI) and right posterior inferior (RPI)]. Each region of interest (ROI) consisted of a seven-electrode cluster. See Fig. 1 for scalp topography of the eight ROIs. Regions included in the ANOVA depended on the time interval of interest, such that only the four anterior regions were used for the early and late frontal effects (LAI, RAI, LAS, RAS) and only the posterior regions were used for the parietal effect (LPS, RPS, LPI, RPI). To understand the effect of aging on the neural correlates of the picture superiority effect, we performed a repeated measures ANOVA with the factors of group (old, young), condition (W–W, P–P), item type (old, new) and ROI for our three time intervals. Follow-up *t*-tests were performed as necessary. Older and younger adults grand average hit and correct rejection ERP waveforms for our two study-test condition comparisons can be seen in Figs. 2 and 3. In addition, old/new scalp topographies for the older and younger adult groups can be seen in Fig. 4. Please note that all 50 ms topographic maps represent an average of 50 ms going forward from the labeled time, such that 0 ms is the average from 0 to 49 ms, etc. Finally, results of the paired-sample *t*-tests at each region of interest for the two study-test condition comparisons can be seen in Fig. 5. Only significant statistics will be discussed.

For the early frontal effect, the ANOVA revealed an effect of item type [$F(1, 32) = 13.490$, $p = 0.001$], indicating that old

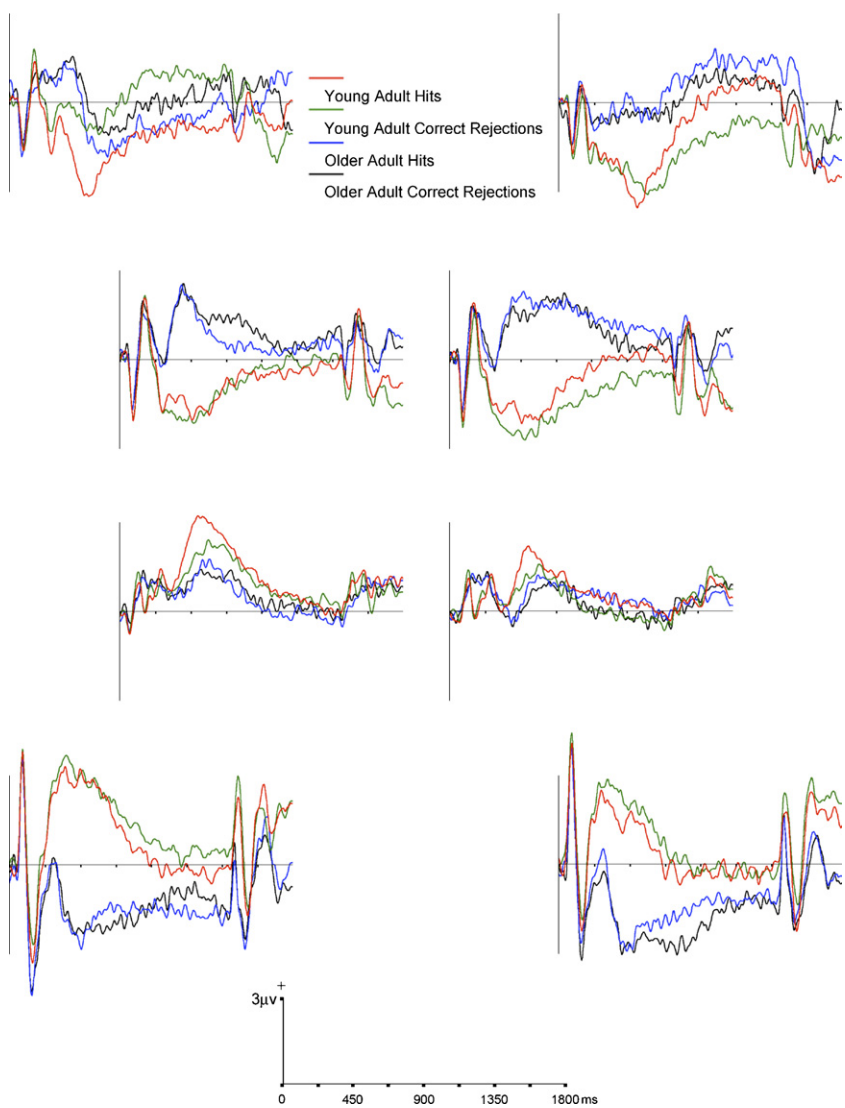

Fig. 2. Older and young adult grand average hit and correct rejection ERP waveforms for the word–word condition for the eight regions of interest.

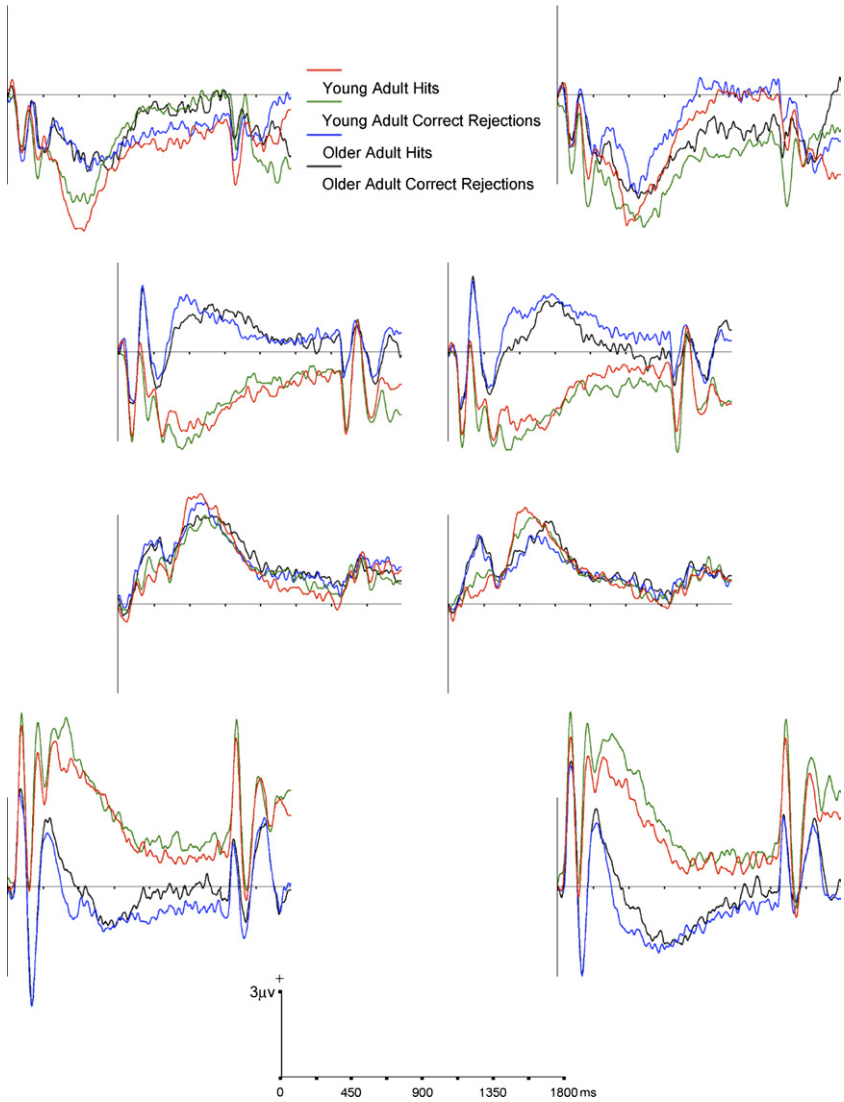

Fig. 3. Older and young adult grand average hit and correct rejection ERP waveforms for the picture–picture condition for the eight regions of interest.

items were more positive than new items. There was also an interaction of item type and condition [$F(1, 32) = 5.235$, $p = 0.029$] such that the difference between old and new items was greater for the picture–picture condition than for the word–word condition, and an interaction of item type and ROI [$F(3, 96) = 7.608$, $p = 0.001$], indicating that old items were more positive than new items at superior frontal ROIs compared to inferior frontal ROIs (LAS, RAS > LAI, RAI). The ANOVA also revealed an effect of group [$F(1, 32) = 27.634$, $p < 0.001$] and an interaction of group and ROI [$F(3, 96) = 3.616$, $p = 0.035$]. Finally, there was an interaction of condition and ROI [$F(3, 96) = 17.640$, $p < 0.001$], indicating that frontal regions were more positive for the picture–picture condition than for the word–word condition. Follow-up analyses showed that the old/new effect was greater in magnitude for the word–word condition at the left superior frontal (LAS) region [$t(32) = 2.253$, $p = 0.031$] for the younger adults than for the older adults. There were no old/new differences in the picture–picture condition between the two groups. Due to the interaction of item type and condition, we performed post hoc t-tests at each frontal ROI within-subjects for the older adults. Results of these analyses showed that the magnitude of the early frontal effect was greater for the picture–picture condition than for the word–word condition at the two superior frontal regions, LAS [$t(16) = 2.809$, $p = 0.013$] and RAS [$t(16) = 3.152$, $p = 0.006$].

Results of the ANOVA for the 500–800 ms time interval revealed no main effect of item type. However, there was an interaction of item type and ROI [$F(3, 96) = 5.246$, $p = 0.007$], and a three-way interaction of item type, ROI and group [$F(3, 96) = 4.764$, $p = 0.011$] indicating that the scalp topography of the parietal effect differed between the younger and older adults. Follow-up t-tests revealed that the old/new effect for the word–word condition was larger in magnitude for the younger adults than for the older adults at the left parietal (LPS) region [$t(32) = 2.322$, $p = 0.027$], whereas this effect was greater in magnitude for the older adults compared to the younger adults at the right occipital (RPI) region [$t(32)$ 3.063, $p = 0.005$]. There were no between-group differences

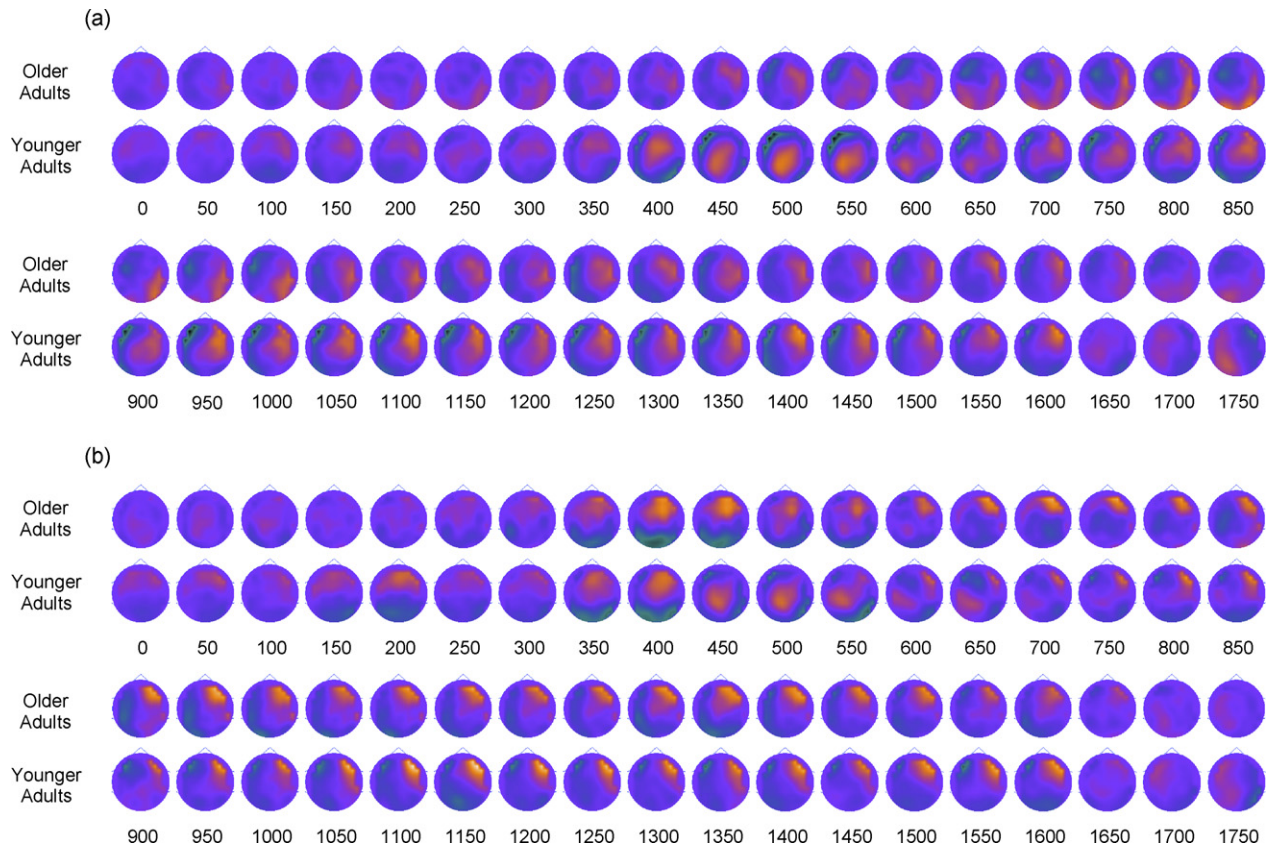

Fig. 4. Older and younger adult old/new scalp topography maps for (a) word–word and (b) picture–picture conditions. Topographies are presented in 50 ms averages going forward.

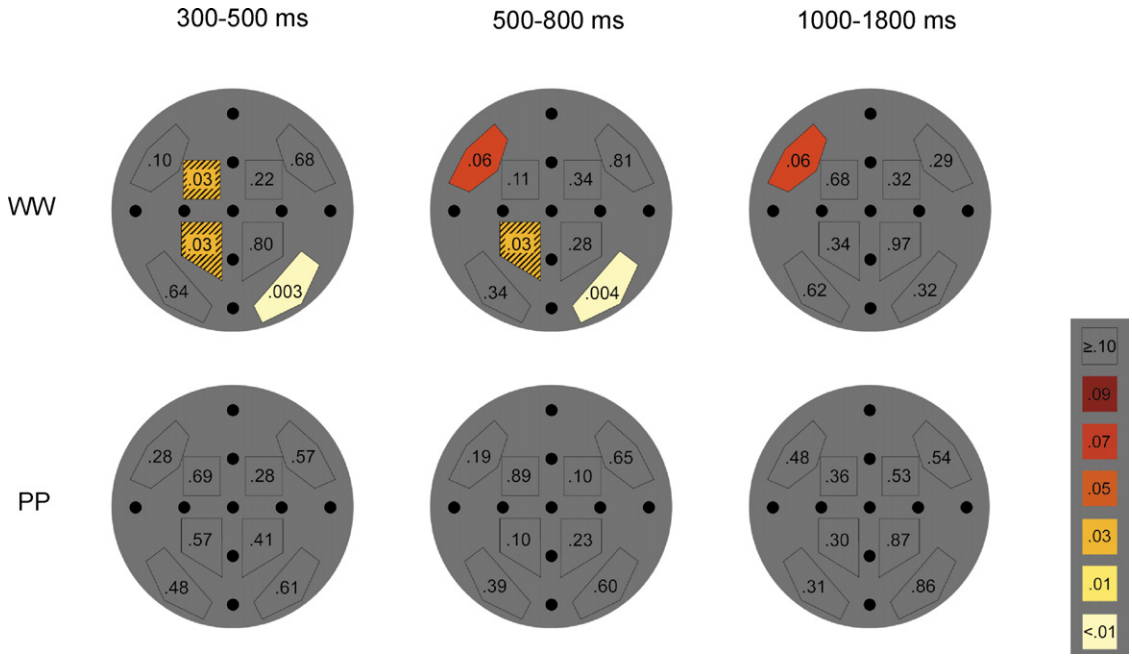

Fig. 5. Topographic maps displaying the between-subject significance levels of the *t*-test comparisons [*t*(32)] between old/new scalp topographies for word–word and picture–picture comparisons. The maps show each region of interest during each time interval of interest. Clear *p*-values indicate a positive *t*-statistic, cross-hatched *p*-values indicate a negative *t*-statistic.

in the parietal old/new effect for the picture–picture condition.

For the late frontal effect, the ANOVA for the 1000–1800 ms time interval revealed an effect item type [$F(1, 32) = 4.722$, $p = 0.037$] such that old items were more positive than new items. There was also an interaction of item type and ROI [$F(3, 96) = 25.214$, $p < 0.001$] indicating that old items were more positive than new items at right frontal regions compared to left frontal regions (RAI, RAS > LAI, LAS). The ANOVA also revealed an effect of group [$F(1, 32) = 11.529$, $p = 0.002$], an interaction of group and ROI [$F(3, 96) = 3.637$, $p = 0.029$] and a three-way interaction of group, ROI and condition [$F(3, 96) = 4.200$, $p = 0.025$]. Follow-up t-tests revealed that both groups showed the typical old/new effect at right frontal regions, but that both groups showed a reverse old/new effect (new items more positive than old items) at left frontal regions. This reverse old/new effect for the word–word condition was marginally smaller in magnitude for the older adults compared to the younger adults at the left inferior frontal (LAI) region [$t(16) = 1.993$, $p = 0.055$]. There were no between-group differences in the late frontal old/new effect for the picture–picture condition.

4. Discussion

The present study set out to better understand the effect of aging on the neural basis of the picture superiority effect. To accomplish this, we examined the recognition memory performance and the electrical activity of the brain during recognition of pictures and words in healthy older adults compared to younger adults. Our behavioral results showed that although both groups demonstrated a clear picture superiority effect, the older adults benefited from pictures to a greater extent than the younger adults. Memory accuracy was similar, but numerically better, for the older adult group compared to the younger adult group for pictures. However, for words, memory accuracy trended towards worse performance for the older adults compared to the younger adults. The ERP results helped to explain these behavioral findings. We found no differences in the early frontal effect, the parietal effect, or late frontal effect between-subjects for the picture–picture condition, and the scalp topographies showed a similar pattern of activity throughout the sampling epoch for both younger and older adults. However, the results revealed several significant differences between the two groups for the word–word condition.

Between-group differences for the word–word condition were evident during the early frontal effect 300–500 ms time interval. Here, there was a larger old/new effect for the younger adults than for the older adults at left superior frontal electrode sites. The scalp topographies for the word–word condition showed a robust old/new effect for the younger adult group at bilateral frontal regions from approximately 300–450 ms. In contrast, the scalp topographies for the older adults during this time interval showed a more right lateralized old/new effect that was not as robust as the young adults. This time interval has been previously associated with familiarity, and the results suggest that perhaps the process of familiarity for words is relatively impaired in the older adult group. To further aid our understanding of the picture superiority effect in older adults, we turn now to our within-subject comparisons between the word–word and picture–picture conditions. Here, we found that pictures were able to "restore" the impaired old/new differences at bilateral superior frontal electrode sites observed with words.

We also found distinct parietal effect differences between the two groups for the word–word condition. Here, the old/new effect was larger at left parietal electrode sites for the younger adults compared to the older adults. However, the old/new effect was larger for the older adults compared to the younger adults at right occipital electrode sites. The scalp topographies showed that the parietal effect begins earlier and is much more robust for the younger adults for the word–word condition. In addition, the older adults initially showed weak parietal activity and then showed pronounced occipital activity. This increase in parieto-occipital activity during a recognition memory task is consistent with recent fMRI (Daselaar, Fleck, & Cabeza, 2006; Daselaar, Fleck, Dobbins, et al., 2006; Yonelinas, Otten, Shaw, & Rugg, 2005) and magnetoencephalographic (Aine et al., 2006) evidence in healthy older adults. We believe that there are three likely hypotheses – which may be different facets of the same phenomena – as to what might be contributing to this robust posterior activity during the word–word condition.

First, this parieto-occipital activity might reflect differences in the process of recollection for older and younger adults. Li et al. (2004) suggested that older and younger adults might differ in the types of information they attempt to retrieve. These authors speculated that whereas younger adults tend to rely on retrieval of abstract or conceptual information, older adults tend to rely on retrieval of visual and perceptual information. This suggestion is supported by research demonstrating that aging affects conceptual, but not perceptual memory processes (Stuart, Patel, & Bhagrath, 2006). If older adults are attempting to retrieve more perceptual-type information, this may account for the shift to more posterior or occipital activity during recollection.

A second hypothesis for the enhanced parieto-occipital activity is that older adults are attempting to reactivate a visual representation or mental image of the studied item. Previous imaging research has shown that primary visual areas are activated when subjects engage in mental imagery (Kosslyn, Thompson, Kim, & Alpert, 1995), and these regions are reactivated at retrieval (Johnson & Rugg, 2007). If older adults are aware of their degraded verbal memory, perhaps mental imagery might be used as a strategy to help boost their verbal memory.

Finally, the enhanced occipital activity might reflect an increased activation of familiarity-based areas of the brain. Daselaar, Fleck, Dobbins, et al. (2006) used fMRI to dissociate familiarity and recollection within posterior brain regions and found that activations associated with familiarity in parieto-occipital regions were preserved in aging, whereas activations associated with recollection in parieto-temporal regions were attenuated. In fact, the authors reported that parieto-occipital regions associated with familiarity actually showed increased activation, perhaps compensating for reduced activation of regions associated with recollection. The close proximity of the familiarity-related parieto-occipital region to secondary visual

cortex may implicate this region in visuo-perceptual functions (Daselaar, Fleck, Cabeza, 2006; Daselaar, Fleck, Dobbins, et al., 2006). This is consistent with Yonelinas (2002) who suggested familiarity is more dependent on perceptual processes. Whether one or all of these related hypotheses are correct remains unclear. Future studies examining these possibilities could help to explain the robust parieto-occipital activity seen in older adults during the 500–800 ms time interval.

Both a diminished parietal effect and impaired recollection of words have been reported in older adults (Daselaar, Fleck, Cabeza, 2006; Daselaar, Fleck, Dobbins, et al., 2006; Fjell et al., 2005; Joyce et al., 1998; Madden et al., 1999; Morcom & Rugg, 2004; Rugg et al., 1997; Swick & Knight, 1997). Fjell et al. (2005) found that not only was the parietal effect for words diminished in older adults aged 70–82, but also that there was a linear decline in the parietal effect evident in middle-aged subjects from 46 to 69 years of age. The authors suggested that the amount of information retrieved likely decreases with age. A long-standing hypothesis for impaired recollection in older adults is that there is an age-related decline in attentional resources at encoding (Park et al., 1989; Salthouse, 1994). Indeed, if attentional resources were not effectively allocated during encoding, the retrieval of the studied item would be difficult. However, the retrieval of distinctive stimuli such as pictures may not have the same attentional requirements as word stimuli and may make it easier for older adults to recollect them. While we do not believe older adults are incapable of using recollection to support their memorial decisions regarding words, it is likely that the overall quantity and/or quality of their recollective experience is greatly diminished in this modality compared to pictures.

The late frontal effect has been associated with post-retrieval monitoring and verification, and is typically associated with a robust old/new effect at right prefrontal electrode sites (Allan et al., 1998; Rugg & Wilding, 2000; Wilding & Rugg, 1996). We found no between-group differences at right frontal regions during the 1000–1800 ms time interval for either the word–word or picture–picture conditions. These results are consistent with numerous studies suggesting that the late frontal effect appears to be less affected by age (Daselaar, Veltman, Rombouts, Raaijmakers, & Jonker, 2003; Li et al., 2004; Mark & Rugg, 1998; Morcom & Rugg, 2004; Wolk et al., 2005). Recent research has suggested that the late frontal effect may reflect other processes of the frontal lobes not related to post-retrieval monitoring, such as decision making and memory confidence (Dobbins & Han, 2006; Fleck, Daselaar, Dobbins, & Cabeza, 2006). Ally and Budson (2007) speculated that the late frontal effect may also reflect activity associated with executive processing that helps direct conscious memory retrieval or multiple memorial search attempts. For the older adults in the current study who appear to have impaired recollection of words, perhaps the late frontal activity reflects prefrontal regions working to confirm a response based on other processes such as familiarity. Indeed, the frontal lobes have been implicated in response inhibition (Shimamura, 1995), which is critical to the suppression of responding based on familiarity alone. Numerous investigations have found that the frontal lobes are involved in distinguishing between identical versus highly similar and familiar items, and thus are important in avoiding false recognition (Budson et al., 2002; Delbecq-Derouesne, Beauvois, & Shallice, 1990; Henson, Rugg, Shallice, Josephs, & Dolan, 1999; Henson, Shallice, & Dolan, 1999; Melo, Winocur, & Moscovitch, 1999; Parkin, Bindschaedler, Harsent, & Metzler, 1996; Parkin, Ward, Bindschaedler, Squires, & Powell, 1999; Rapcsak et al., 1998; Rapcsak et al., 2001; Schacter, Curran, Galluccio, Milberg, & Bates, 1996).

In conclusion, the results of the present investigation show that older adult memory accuracy for pictures was comparable to that of younger adults. However, memory for words was somewhat impaired. Helping to explain these findings, our ERP results suggested that pictures enable older adults to engage memorial neural systems in a very similar manner to young adults. The early frontal effect, parietal effect, and late frontal effect were all indistinguishable between older and younger adults for pictures. In contrast, for words, the early frontal and parietal effects were significantly diminished for the older adults compared to the younger adults. These two old/new effects have been linked to familiarity and recollection, respectively, and our results suggest that these processes are impaired for word-based memory in the course of healthy aging. Our results also demonstrated that the late frontal effect is indistinguishable for older adults and younger adults for both pictures and words. The late frontal old/new effect has been linked to several retrieval and post-retrieval-based processes that may reflect executive involvement in memory-related searches and decisions. The findings of this study suggest that pictures can allow older adults to compensate for their impaired memorial processes, and may allow memorial components to function more effectively in older adults. These findings help us to understand healthy memory in older adults, and may serve as a model to understand how memory is affected in diseases of aging such as Alzheimer's. Future studies will be able to investigate whether older adults and memory-disordered patients can create their own pictures– by using mental imagery – to compensate for their impaired memory for words.

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References

Achim, A. M., & Lepage, M. (2005). Dorsolateral prefrontal cortex involvement in memory post-retrieval monitoring revealed in both item and associative recognition tests. *NeuroImage*, *24*, 1113–1121.

Addis, D. R., & McAndrews, M. P. (2006). Prefrontal and hippocampal contributions to the generation and binding of semantic associations during successful encoding. *NeuroImage*, *33*, 1194–1206.

Adjutant General's Office. (1944). *Army individual test battery: Manual of directions and scoring*. Washington, DC: War Department.

Aine, C. J., Woodruff, C. C., Knoefel, J. E., Adair, J. C., Hudson, D., Qualls, C., et al. (2006). Aging: Compensation or maturation? *NeuroImage*, *32*, 1891–1904.

Allan, K., Wilding, E. L., & Rugg, M. D. (1998). Electrophysiological evidence for dissociable processes contributing to recollection. *Acta Psychologica*, *98*, 231–252.

Ally, B. A., & Budson, A. E. (2007). The worth of pictures: Using high density event-related potentials to understand the memorial power of pictures and the dynamics of recognition memory. *NeuroImage*, *35*, 378–395.

Balota, D. A., Dolan, P. O., & Duchek, J. M. (2000). Memory changes in healthy older adults. In E. Tulving & F. I. M. Craik (Eds.), *The Oxford handbook of memory* (pp. 395–409). New York: Oxford University Press.

Budson, A. E., Droller, D. B., Dodson, C. S., Schacter, D. L., Rugg, M. D., Holcomb, P. J., et al. (2005). Electrophysiological dissociation of picture versus word encoding: The distinctiveness heuristic as a retrieval orientation. *Journal of Cognitive Neuroscience*, *17*, 1181–1193.

Budson, A. E., Sullivan, A. L., Mayer, E., Daffner, K. R., Black, P. M., & Schacter, D. L. (2002). Suppression of false recognition in Alzheimer's disease and in patients with frontal lobe lesions. *Brain*, *125*, 2750–2765.

Cabeza, R., Anderson, N. D., Locantore, J. K., & McIntosh, A. R. (2002). Aging gracefully: Compensatory brain activity in high-performing older adults. *NeuroImage*, *17*, 1394–1402.

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: Lawrence Erlbaum Associates Inc.

Craik, F. I., Naveh-Benjamin, M., Ishaik, G., & Anderson, N. D. (2000). Divided attention during encoding and retrieval: Differential control effects? *Journal of Experimental Psychology. Learning, Memory and Cognition*, *26*, 1744–1749.

Curran, T. (2000). Brain potentials of recollection and familiarity. *Memory & Cognition*, *28*, 923–938.

Curran, T. (2004). Effects of attention and confidence on the hypothesized ERP correlates of recollection and familiarity. *Neuropsychologia*, *42*, 1088–1106.

Curran, T., DeBuse, C., Woroch, B., & Hirshman, E. (2006). Combined pharmacological and electrophysiological dissociation of familiarity and recollection. *The Journal of Neuroscience*, *26*, 1979–1985.

Daselaar, S. M., Fleck, M. S., & Cabeza, R. (2006). Triple dissociation in the medial temporal lobes: Recollection, familiarity, and novelty. *Journal of Neurophysiology*, *96*, 1902–1911.

Daselaar, S. M., Fleck, M. S., Dobbins, I. G., Madden, D. J., & Cabeza, R. (2006). Effects of healthy aging on hippocampal and rhinal memory functions: An event-related fMRI study. *Cerebral Cortex*, *16*, 1771–1782.

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

Davidson, P. S., & Glisky, E. L. (2002). Neuropsychological correlates of recollection and familiarity in normal aging. *Cognitive, Affective & Behavioral Neuroscience*, *2*, 174–186.

Delbecq-Derouesne, J., Beauvois, M. F., & Shallice, T. (1990). Preserved recall versus impaired recognition. A case study. *Brain*, *113*, 1045–1074.

Dien, J. (1998). Addressing misallocation of variance in principal components analysis of event-related potentials. *Brain Topography*, *11*, 43–55.

Dobbins, I. G., & Han, S. (2006). Isolating rule- versus evidence-based prefrontal activity during episodic and lexical discrimination: A functional magnetic resonance imaging investigation of detection theory distinctions. *Cerebral Cortex*, *16*, 1614–1622.

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.

Duzel, E., Yonelinas, A. P., Mangun, G. R., Heinze, H. J., & Tulving, E. (1997). Event-related brain potential correlates of two states of conscious awareness in memory. *Proceedings of the National Academy of Sciences of the United States of America*, *94*, 5973–5978.

Ecker, U. K. H., Zimmer, H. D., Groh-Bordin, C., & Meckinger, A. (2007). Context effects on familiarity are familiarity effects of context—An electrophysiological study. *International Journal of Psychophysiology*, *64*, 146–156.

Fjell, A. M., Walhovd, K. B., & Reinvang, I. (2005). Age-differences in verbal recognition memory revealed by ERP. *Clinical EEG and Neuroscience*, *36*, 176–187.

Fleck, M. S., Daselaar, S. M., Dobbins, I. G., & Cabeza, R. (2006). Role of prefrontal and anterior cingulate regions in decision-making processes shared by memory and nonmemory tasks. *Cerebral Cortex*, *16*, 162301630.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-Mental State". A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatry Research*, *12*, 189–198.

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.

Gallo, D. A., Kensinger, E. A., & Schacter, D. L. (2006). Prefrontal activity and diagnostic monitoring of memory retrieval: Fmri of the criterial recollection task. *Journal of Cognitive Neuroscience*, *18*, 135–148.

Goldmann, R. E., Sullivan, A. L., Droller, D. B., Rugg, M. D., Curran, T., Holcomb, P. J., et al. (2003). Late frontal brain potentials distinguish true and false recognition. *Neuroreport*, *14*, 1717–1720.

Henson, R. N., Rugg, M. D., Shallice, T., Josephs, O., & Dolan, R. J. (1999). Recollection and familiarity in recognition memory: An event-related functional magnetic resonance imaging study. *The Journal of Neuroscience*, *19*, 3962–3972.

Henson, R. N., Shallice, T., & Dolan, R. J. (1999). Right prefrontal cortex and episodic memory retrieval: A functional MRI test of the monitoring hypothesis. *Brain*, *122*, 1367–1381.

Howard, M. W., Bessette-Symons, B., Zhang, Y., & Hoyer, W. J. (2006). Aging selectively impairs recollection in recognition memory for pictures: Evidence from modeling and receiver operating characteristic curves. *Psychology and Aging*, *21*, 96–106.

Jacoby, L. L. (1999). Ironic effects of repetition: Measuring age-related differences in memory. *Journal of Experimental Psychology. Learning, Memory and Cognition*, *25*, 3–22.

Jennings, J. M., & Jacoby, L. L. (1993). Automatic versus intentional uses of memory: Aging, attention, and control. *Psychology and Aging*, *8*, 283–293.

Jennings, J. M., & Jacoby, L. L. (1997). An opposition procedure for detecting age-related deficits in recollection: Telling effects of repetition. *Psychology and Aging*, *12*, 352–361.

Johnson, J. D., & Rugg, M. D. (2007). Recollection and the reinstatement of encoding related cortical activity. *Cerebral Cortex*, *17*, 2507–2515.

Joyce, C. A., Paller, K. A., McIsaac, H. K., & Kutas, M. (1998). Memory changes with normal aging: Behavioral and electrophysiological measures. *Psychophysiology*, *35*, 669–678.

Kosslyn, S. M., Thompson, W. L., Kim, I. J., & Alpert, N. M. (1995). Topographical representations of mental images in primary visual cortex. *Nature*, *378*, 496–498.

Langley, M. M., Cleary, A. M., Kostic, B. N., & Woods, J. A. (2008). Picture recognition without picture identification: A method for assessing the role of perceptual information in familiarity-based picture recognition. *Acta Psychologica*, *127*, 103–113.

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.

Light, L. L., Prull, M. W., La Voie, D. J., & Healy, M. R. (1999). Dual-process theories of memory in old age. In T. J. Perfect & E. A. May-lor (Eds.), *Models of cognitive aging* (pp. 238–300). Oxford: Oxford University Press.

Mack, W. J., Freed, D. M., Williams, B. W., & Henderson, V. W. (1992). Boston naming test: Shortened versions for use in alzheimer's disease. *Journal of Gerontology*, *47*, P154–P158.

Madden, D. J., Gottlob, L. R., Denny, L. L., Turkington, T. G., Provenzale, J. M., Hawk, T. C., et al. (1999). Aging and recognition memory: Changes in regional cerebral blood flow associated with components of reaction time distributions. *Journal of Cognitive Neuroscience*, *11*, 511–520.

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

Melo, B., Winocur, G., & Moscovitch, M. (1999). False recall and false recognition: An examination of the effects of selective and combined lesions to the medial temporal lobe/diencephalon and frontal lobe structures. *Cognitive Neuropsychology*, *16*, 343–359.

Mintzer, M. Z., & Snodgrass, J. G. (1999). The picture superiority effect: Support for the distinctiveness model. *The American Journal of Psychology*, *112*, 113–146.

Monsch, A. U., Bondi, M. W., Butters, N., Salmon, D. P., Katzman, R., & Thal, L. J. (1992). Comparisons of verbal fluency tasks in the detection of dementia of the Alzheimer type. *Archives of Neurology*, *49*, 1253–1258.

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

Morris, J. C., Heyman, A., Mohs, R. C., Hughes, J. P., van Belle, G., Fillenbaum, G., et al. (1989). The consortium to establish a registry for Alzheimer's disease (CERAD). Part i. Clinical and neuropsychological assessment of Alzheimer's disease. *Neurology*, *39*, 1159–1165.

Nielsen-Bohlman, L., & Knight, R. T. (1995). Prefrontal alterations during memory processing in aging. *Cerebral Cortex*, *5*, 541–549.

Park, D. C., Puglisi, J. T., & Sovacool, M. (1983). Memory for pictures, words, and spatial location in older adults: Evidence for pictorial superiority. *Journal of Gerontology*, *38*, 582–588.

Park, D. C., Smith, A. D., Dudley, W. N., & Lafronza, V. N. (1989). Effects of age and a divided attention task presented during encoding and retrieval on memory. *Journal of Experimental Psychology. Learning, Memory and Cognition*, *15*, 1185–1191.

Parkin, A. J., Bindschaedler, C., Harsent, L., & Metzler, C. (1996). Pathological false alarm rates following damage to the left frontal cortex. *Brain and Cognition*, *32*, 14–27.

Parkin, A. J., Ward, J., Bindschaedler, C., Squires, E. J., & Powell, G. (1999). False recognition following frontal lobe damage: The role of encoding factors. *Cognitive Neuropsychology*, *16*, 243–265.

Prull, M. W., Dawes, L. L., Martin, A. M., 3rd, Rosenberg, H. F., & Light, L. L. (2006). Recollection and familiarity in recognition memory: Adult age differences and neuropsychological test correlates. *Psychology and Aging*, *21*, 107–118.

Rapcsak, S. Z., Kaszniak, A. W., Reminger, S. L., Glisky, M. L., Glisky, E. L., & Comer, J. F. (1998). Dissociation between verbal and autonomic measures of memory following frontal lobe damage. *Neurology*, *50*, 1259–1265.

Rapcsak, S. Z., Nielsen, L., Littrell, L. D., Glisky, E. L., Kaszniak, A. W., & Laguna, J. F. (2001). Face memory impairments in patients with frontal lobe damage. *Neurology*, *57*, 1168–1175.

Rugg, M. D., Fletcher, P. C., Allan, K., Frith, C. D., Frackowiak, R. S., & Dolan, R. J. (1998). Neural correlates of memory retrieval during recognition memory and cued recall. *NeuroImage*, *8*, 262–273.

Rugg, M. D., Mark, R. E., Gilchrist, J., & Roberts, R. C. (1997). ERP repetition effects in indirect and direct tasks: Effects of age and interitem lag. *Psychophysiology*, *34*, 572–586.

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

Rybash, J. M., & Hoyer, W. J. (1996). Process dissociation procedure reveals age differences in unconscious influences on memory for possible and impossible objects. *Aging, Neuropsychology, & Cognition*, *3*, 251–263.

Salthouse, T. A. (1994). Aging associations: Influence of speed on adult age differences in associative learning. *Journal of Experimental Psychology. Learning, Memory and Cognition*, *20*, 1486–1503.

Schacter, D. L., Curran, T., Galluccio, L., Milberg, W. P., & Bates, J. F. (1996). False recognition and the right frontal lobe: A case study. *Neuropsychologia*, *34*, 793–808.

Schloerscheidt, A. M., & Rugg, M. D. (2004). The impact of change in stimulus format on the electrophysiological indices of recognition. *Neuropsychologia*, *42*, 451–466.

Schnyer, D. M., Nicholls, L., & Verfaellie, M. (2005). The role of vmpc in metamemorial judgments of content retrievability. *Journal of Cognitive Neuroscience*, *17*, 832–846.

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.

Shepard, R. N. (1976). Recognition memory for words, sentences, and pictures. *Journal of Verbal Learning and Verbal Behavior*, *6*, 156–163.

Shimamura, A. P. (1995). Memory and the prefrontal cortex. *Annals of the New York Academy of Sciences*, *769*, 151–159.

Smith, A. D. (1996). Memory. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the psychology of aging*. San Diego, CA: Academic Press Inc.

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.

Stuart, G. P., Patel, J., & Bhagrath, N. (2006). Ageing affects conceptual but not perceptual memory processes. *Memory*, *14*, 345–358.

Swick, D., & Knight, R. T. (1997). Event-related potentials differentiate the effects of aging on word and nonword repetition in explicit and implicit memory tasks. *Journal of Experimental Psychology. Learning, Memory and Cognition*, *23*(1), 123–142.

Titov, N., & Knight, R. G. (1997). Adult age differences in controlled and automatic memory processing. *Psychology and Aging*, *12*, 565–573.

Toth, J. P. (1996). Conceptual automaticity in recognition memory: Levels-of-processing effects on familiarity. *Canadian Journal of Experimental Psychology*, *50*, 123–138.

Toth, J. P., & Parks, C. M. (2006). Effects of age on estimated familiarity in the process dissociation procedure: The role of noncriterial recollection. *Memory & Cognition*, *34*, 527–537.

Trott, C. T., Friedman, D., Ritter, W., & Fabiani, M. (1997). Item and source memory: Differential age effects revealed by event-related potentials. *Neuroreport*, *8*, 3373–3378.

Vilberg, K. L., Moosavi, R. F., & Rugg, M. D. (2006). The relationship between electrophysiological correlates of recollection and amount of information retrieved. *Brain Research*, *1122*, 161–170.

Wagner, A. D., Shannon, B. J., Kahn, I., & Buckner, R. L. (2005). Parietal lobe contributions to episodic memory retrieval. *Trends in Cognitive Science*, *9*, 445–453.

Wilding, E. L., & Rugg, M. D. (1996). An event-related potential study of recognition memory with and without retrieval of source. *Brain*, *119*, 889–905.

Winograd, E., Smith, A. D., & Simon, E. W. (1982). Aging and the picture superiority effect in recall. *Journal of Gerontology*, *37*, 70–75.

Wolk, D. A., Schacter, D. L., Berman, A. R., Holcomb, P. J., Daffner, K. R., & Budson, A. E. (2005). Patients with mild alzheimer's disease attribute conceptual fluency to prior experience. *Neuropsychologia*, *43*, 1662–1672.

Woodruff, C. C., Hayama, H. R., & Rugg, M. D. (2006). Electrophysiological dissociation of the neural correlates of recollection and familiarity. *Brain Research*, *1100*, 125–135.

Yonelinas, A. P. (2001). Components of episodic memory: The contribution of recollection and familiarity. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, *356*, 1363–1374.

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.

Yonelinas, A. P., & Jacoby, L. L. (1996). Noncriterial recollection: Familiarity as automatic, irrelevant recollection. *Consciousness and Cognition*, *5*, 131–141.

Yonelinas, A. P., Otten, L. J., Shaw, K. N., & Rugg, M. D. (2005). Separating the brain regions involved in recollection and familiarity in recognition memory. *The Journal of Neuroscience*, *25*, 3002–3008.