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Age-related differences in prestimulus subsequent memory effects assessed with event-related potentials

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Abstract

Prestimulus subsequent memory effects (preSMEs) – differences in neural activity elicited by a task cue at encoding that are predictive of later memory performance – are thought to reflect differential engagement of preparatory processes that benefit episodic memory encoding. The present experiment investigated age differences in preSMEs indexed by differences in ERP amplitude just prior to the onset of a study event. Healthy young and older human adults (both males and females) incidentally encoded words for a subsequent memory test. Each study word was preceded by a task cue that signaled the judgment to perform on the word. Words were presented for either a short (300 ms) or a long (1000 ms) duration with the aim of placing differential benefits on engaging the preparatory processes initiated by the task cue. ERPs associated with subsequent successful and unsuccessful recollection, operationalized here by source memory accuracy, were estimated time-locked to the onset of the task cue. In a late time-window (1000-2000 ms following cue onset), young adults demonstrated frontally-distributed preSMEs in both the short and long conditions, albeit with opposite polarities in the two conditions. This finding suggests that preSMEs in young adults are sensitive to task demands. Although older adults showed no evidence of preSMEs in the same late time window, significant preSMEs were observed in an earlier time window (500-1000 ms) in both encoding conditions. These results are broadly consistent with the proposal that older adults differ from their young counterparts in how they engage preparatory processes during memory encoding.

Introduction

Neural activity elicited as an event is experienced is predictive of whether the event will be subsequently remembered or forgotten (for review, see Kim, 2011; Rugg, Johnson, & Uncapher, 2015). In addition to what might be called 'post-stimulus' subsequent memory effects (SMEs) – differences in neural activity elicited by events that are subsequently remembered or forgotten – there is growing evidence that processes engaged in the second or so *before* an event is encountered also predict subsequent memory performance. ERP (e.g., Galli, Choy, & Otten, 2012; 2013; Gruber & Otten, 2010; Otten, Quayle, Akram, Ditewig, & Rugg, 2006; Otten, Quayle, & Puvaneswaran, 2010) and fMRI (e.g., Addante, de Chastelaine, & Rugg, 2015; de Chastelaine & Rugg, 2015; Park & Rugg, 2010) studies have investigated 'prestimulus' SMEs (preSMEs) – differences in neural activity elicited by task cues preceding encoding events. In young adults, preSMEs are typically maximal in the second or so prior to the onset of the study event, and usually take the form of a sustained negative deflection over fronto-central electrodes for task cues preceding remembered relative to forgotten events (e.g., Otten et al., 2006; Otten et al., 2010). Although there are well-documented age differences in SMEs (for review, see Friedman, Nessler, & Johnson, 2007; Maillet & Rajah, 2014a; Spreng, Wojtowicz, & Grady, 2010), it is presently unknown if preSMEs differ with age.

The present experiment addresses the question of age differences in preSMEs using ERPs. To do so, young and older adults studied a list of words for a subsequent memory test while EEG was recorded (see Figure 1). A task cue preceded each study word and instructed participants to make one of two semantic judgments. The primary analysis focused on preSMEs, operationalized here as ERPs time-locked to the onset of the task cue and segregated by whether the word was associated with accurate versus inaccurate source memory.

Although we expected to identify reliable preSMEs in young adults, whether older adults would show evidence of preSMEs is an open question. Two lines of evidence suggest older adults might be impaired at effectively engaging prestimulus processes during encoding. First, preSMEs are associated with recollection (e.g., Otten et al., 2006; 2010; Park & Rugg, 2010), a form of memory highly vulnerable to aging (Koen & Yonelinas, 2014; Schoemaker, Gauthier, & Pruessner, 2014). Second, relative to young individuals, task performance in older adults is more dependent on 'reactive' rather than 'proactive' cognitive processing (e.g., Braver, Paxton, Locke, & Barch, 2009; Jacoby, Shimizu, Velanova, & Rhodes, 2005; Morcom & Rugg, 2004). Taken together, the above findings support the prediction that preSMEs will be reduced or absent in older adults when compared with young adults.

Older adults may however fail to show preSMEs simply because they do not attempt to engage the prestimulus processes (unless task demands incentivize doing so, e.g., Duverne, Motamedinia, & Rugg, 2009; Luo & Craik, 2008). For example, although older adults do not spontaneously engage material-dependent 'retrieval orientations', they can do so when task demands are sufficiently high (Duverne et al., 2009; Morcom & Rugg, 2004). Therefore, it is important to rule out the possibility that age-related reductions in preSMEs are merely a failure, rather than an inability, to engage preparatory processes. We attempted to address this issue by manipulating the presentation duration of the study items (300 ms vs. 1000 ms), thereby manipulating the benefit of engaging pre-stimulus preparatory processing (i.e., we assume that the relatively limited perceptual availability of the study word in the short duration condition places a premium on prestimulus preparation). Our expectation was that the highest likelihood of finding preSMEs in older adults would be in the short encoding condition, that is, the condition in which the incentive to engage prestimulus preparatory processes is highest.

Materials and Methods

Ethics Statement

The Institutional Review Board of the University of Texas at Dallas approved the experimental procedures described below. All participants provided written informed consent prior to participating in each experimental session.

Participants

Twenty-four older and 24 young participants were included in the analyses reported in this paper (see Table 1 for characteristics of the sample). Participants were compensated at a rate of $30 an hour for their time and also received travel expenses. We recruited young and older adults from the University of Texas at Dallas and the greater Dallas metropolitan area. All participants were right-handed, reported having normal or corrected-to-normal vision, and scored 27 or more on the Mini-Mental State Examination (MMSE). Exclusion criteria included a history of cardiovascular disease (other than treated hypertension), diabetes, psychiatric disorder, illness or trauma affecting the central nervous system, substance abuse, and self-reported current or recent use of psychotropic medication or sleeping aids.

Data from an additional 7 participants who underwent EEG recording were excluded for the following reasons: 2 young adult females and 2 older adult males were excluded due to insufficient (fewer than 15) artifact-free epochs in a bin of interest, 1 young adult male and 1 older adult male were excluded because of significant artifacts in the ERP that could not be corrected or removed (as jointly determined by the first and last author), and 1 older adult male was excluded for failure to understand the test instructions (incorrect use of Remember/Know judgments).

Participants completed a neuropsychological test battery on a separate day prior to the EEG study. The battery included the same measures that we have used in prior studies (cf., de Chastelaine et al., 2016), with the addition of a visual acuity test. Participants were excluded from participating in the EEG study if (1) one or more of the memory measures were more than 1.5 standard deviations below the age- and education-adjusted mean, (2) they had a standard score below 100 on the Wechsler Test of Adult Reading, or (3) two or more scores on non-memory tests were 1.5 standard deviations below the mean. Additionally, participants completed a visual acuity test as part of the neuropsychological test battery. As this measure was not used for screening purposes, and is not relevant to the current study, it will not be discussed further.

Materials

Three hundred and eighty-four nouns from the MRC Psycholinguistic database (Coltheart, 2007) comprised the critical stimuli in this experiment. The words ranged from 4-8 letters in length (M = 5.32, SD = 1.21), from 1-40 in Kucera-Francis frequency (M = 13.33, SD = 10.25) (Kucera & Francis, 1967) and concreteness ratings from 500-662 (M = 583.90, SD = 31.99). These words were used to generate 24 stimulus sets that were yoked across young and older participants.

For each stimulus set, 256 words were assigned to be presented in the study list and were randomly divided into 4 groups of 64 words. The four groups were assigned to one of the four cells formed by crossing the encoding duration variable (short versus long encoding duration) and the semantic judgment performed during the study phase (Manmade versus Shoebox). The word list for the test phase comprised the 256 words from the study phase and remaining 128 words as new items on the recognition memory test.

An additional 24 words with similar characteristics to those of the critical stimuli were used in the practice phases. The words in each practice list were the same for all participants. In total there were 3 practice study lists (self-paced, speeded, real), each comprising 8 words. In addition, there were two 2 practice test lists (feedback, real). The feedback practice test list consisted of 8 words from the practice study phases and 4 new words. The real practice test phase consisted of 8 words from the practice study phases and 4 new words.

Stimuli were presented via a 22" LCD Monitor (1024 x 768 resolution) using Cogent 2000 software (http://www.vislab.ucl.ac.uk/cogent_2000.php) implemented in Matlab 2012b (www.mathworks.com). Throughout the experiment, the monitor displayed a black background with a white centrally located box (250 x 250 pixels). All stimuli were presented in the center of the screen in Helvetica 32-point font. Note that, as is typical in studies such as this, all timing information given below is uncorrected for the refresh rate of the monitor, and hence varied across trials within a range of ±17ms.

Procedure

Overview. The experiment was completed across two sessions on different days, with the neuropsychological test battery completed in the first session, and the experimental EEG session completed in the second session. The experimental EEG task comprised study and test phases structured similarly to previous studies (Galli et al., 2013; Otten et al., 2006).

Study Phase. The procedure for the critical study phase is schematically depicted in the left half of Figure 1. Participants were presented with four blocks of 64 words that served as the studied items for the subsequent memory test. Half of the blocks were assigned to the short encoding condition, and the remaining half were assigned to the long encoding condition. A break was given halfway through each block. The words were encoded incidentally with no

reference to the subsequent memory test in the instructions. Each word in both the short and long encoding conditions was preceded by a task cue informing participants which one of two judgments they should make about the word. The two possible judgments were ‘Manmade’, whereby participants made a yes/no response as to whether the object denoted by the word was a manmade object, and ‘Shoebox’, which required a yes/no response about whether the object denoted by the word was something that fits inside a shoebox. The cues for the Manmade and Shoebox tasks were a red ‘X’ and ‘O’, respectively. In both the short and long blocks, each trial began with a green fixation cross for 500 ms, which was followed by the presentation of the task cue for 500 ms. After a 1500 ms delay (filled with a black fixation cross), the study word was presented. In the short encoding condition, the word appeared on the screen for 300 ms followed by a 2700 ms black fixation cross that served as the response window. In the long encoding condition, the word appeared on the screen for 1000 ms followed by a 2000 ms black fixation cross that served as the response window. The hand that was used for the Manmade as opposed to the Shoebox judgment was counterbalanced across participants, and they used their index or middle fingers to enter a yes or no response, respectively. Note that the timing of the study trials and inter-trial interval was fixed and hence unaffected by response latency. Participants were instructed to make their responses as quickly but as accurately as possible.

Participants completed three brief practice study phases prior to the critical phase. The three practice study phases comprised (in order) a self-paced practice with feedback, speeded practice with feedback, and a “real” practice phase. In the self-paced practice phase, participants were presented with the trial sequence as described above with the exception that the word remained on the screen until a response was given. After entering a response, participants received feedback as to whether they responded to the correct judgment (i.e., they entered their

judgment using the assigned hand for the Manmade or Shoebox judgments). Feedback as to the accuracy of the yes and no response for either judgment was not provided. In the speeded practice with feedback phase, participants were presented with the full trial sequence described above for the critical study phase, with the exception that after each trial participants were provided feedback as to whether they responded to the correct judgment. In this practice phase, participants were also introduced to the short and long encoding conditions. The purpose of the first two practice study phases was to (1) practice participants in using different hands to answer the two different judgments and (2) instruct participants to respond quickly. The "real" practice phase was identical to the critical study phase in timing, except that the blocks were shorter (4 trials in each encoding condition).

Test Phase. Approximately 15 minutes after completion of the study phase, participants began instruction for the test phase. In the test phase proper (see below for description of the practice phases) participants were presented with studied and new words one at a time and required to make a Remember/Know/New (R/K/N) judgment (Tulving, 1985). Participants were instructed to make a Remember (R) response if they could recollect at least one specific detail from the study phase that was associated with the test item (e.g., the encoding task; a thought that came to mind). Importantly, participants were further instructed that they should be able to explain exactly what they recollected about the word to the experimenter if they made an R response. A Know (K) response was required when participants had high confidence that the word was studied but they were unable to recollect any specific contextual detail about the word when it was encountered in the study phase. The K response was labeled as 'Familiar' in the instructions to participants to avoid confusion between the terms Remember and Know, but we refer to this response option here as Know (or K) to remain consistent with the literature.

Participants were instructed to give a New (N) response if they believed the word did not appear in the list or if they would simply be guessing that the word had been studied.

For words endorsed with an R response, participants were further required to make a source memory judgment in respect of the encoding task (Manmade or Shoebox). This judgment had three possible responses: Manmade, Shoebox, and Don't Know. Participants were instructed to select Manmade or Shoebox if they had high confidence about the encoding task they had performed on the word during encoding. They were instructed to use the Don't Know option if they were not confident or were unable to recollect the encoding task. Thus, an R response followed by a Don't Know source memory response indicated that participants recollected a specific detail or details about the study that did not include the criterial details necessary to support a high confidence source memory decision (i.e., the nature of the encoding task).

It should be noted that the present task differs from prior studies using combined R/K/N and source memory judgments (Duarte, Henson, & Graham, 2008) in two ways. First, we included a Don't Know response alternative on the source memory judgment. Second, source memory judgments were required for trials receiving an R judgment, but not for trials receiving a K judgment. We adopted this procedure on the assumption that, as participants were instructed to give a K response if they were unable to recollect or retrieve *any* specific detail of the study episode, the great majority of source judgments following a K response would have led to a Don't Know response. By restricting the source judgments to items accorded an R judgment we were able to markedly simplify the task instructions and response demands, reducing the likelihood of non-compliance or confusion.

Each trial in the test phase began with a green fixation cross for 500 ms, which was followed by the presentation of the test word for 650 ms, which was followed in turn by a black

fixation cross. Participants were instructed to enter their R/K/N response after the black fixation cross appeared on the screen. The R/K/N response was self-paced, and thus the fixation cross remained on the screen until a response was entered. If participants made a K or N response, the fixation cross remained for an additional 2000 ms, after which the next trial began (i.e., the next green fixation cross). If participants made an R response, the black fixation cross remained on the screen for an additional 500 ms, and was followed by a prompt (the word 'Task?' in red font) to enter the source memory response. The prompt remained on the screen for a maximum of 650 ms, and was replaced with a red fixation cross if a response was still forthcoming. The source memory response was also self-paced, and, once the response was entered, a black fixation cross appeared for 1000 ms before the onset of the next trial. The test phase was broken into 12 equal-length blocks, allowing a short break after every 32 trials.

Prior to the critical test phase there were two practice phases that made use of the words from the practice study phases intermixed with a set of new words. The timing for both of the practice phases followed that described in the preceding paragraph for the critical phase. In the first practice phase, the participant's response selections were displayed on the computer screen at the end of each trial, and they were asked to explain the basis of their judgments. This was to allow the experimenters to provide participants with feedback on their use of the R/K/N responses, and to verify that participants were applying the R/K/N distinction correctly. The second practice phase was identical to the test phase proper, except that a shorter list was employed. Following completion of the critical test phase, participants were debriefed, compensated, and thanked for their participation.

Rationale for the Test Phase

The rationale for including both R/K/N and source memory judgments was to explore whether pre- and post-stimulus SMEs differed for R judgments associated with accurate versus inaccurate source judgments. Contrary to our expectations based on the results from a behavioral pilot study, limited trial counts precluded us from being able to address this question. Instead, we examined pre- and post-stimulus SMEs by operationalizing successful versus unsuccessful recollection in terms of correct and incorrect source memory judgments, respectively. Specifically, source correct trials comprised encoding trials for which the study word went on to receive both an R response and a correct source memory decision. Source incorrect trials comprised trials where the study word subsequently received an R response and either an incorrect or a Don't Know response to the source memory judgment, or trials that subsequently received a K response. Given our assumption that participants would have responded Don't Know (or guessed) on trials accorded a K judgment, this partitioning of trials is analogous to that employed in prior studies where source memory judgments were not combined with the R/K/N procedure (e.g., Koen & Rugg, 2016; Maillet & Rajah, 2014b; Mattson, Wang, de Chastelaine, & Rugg, 2013; Ranganath et al., 2004).

EEG Recording

EEG was recorded continuously during both the study and test phases (only the study data are presented here). The recordings were made from a total of 64 Ag/Ag-Cl electrodes with 58 embedded in an elastic cap (EasyCap; Herrsching-Breitbrunn, Germany; www.easycap.de; montage 11) and 6 affixed directly to the skin. The electrode sites in the cap comprised 6 midline locations (Fpz, Fz, Cz, CPz, PZ, POz) and 26 homotopic electrode pairs (Fp1/2, AF3/4, AF7/8, F1/2, F3/4, F5/6, F7/8, FC1/2, FC3/4, FC5/7, FT7/8, C1/2, C3/4, C5/6, T7/8, CP1/2, CP3/4, CP5/6, TP7/8, P1/2, P3/4, P5/6, P7/8, PO3/4, PO7/8, and O1/O2). Two additional electrodes

were affixed to the left and right mastoid process. Vertical and horizontal EOG were monitored with electrode pairs above and below the right eye, and on the outer canthi of the left and right eyes, respectively. The ground and online reference electrodes were embedded in the cap at sites AFz and FCz, respectively. EEG and EOG channels were digitized at 500 Hz using an amplifier bandpass of .01-70 Hz (3dB points) using the BrainVision Recorder software package (version 1.20.0601, www.brainvision.com). Electrode impedances were adjusted to be less than or equal to 5 kΩ prior to the start of the study phase, and were rechecked and, if necessary, adjusted, during each break.

EEG/ERP Analysis

The EEG data were processed offline in Matlab 2012b (www.mathworks.com) using EEGLAB version 13.5.4 (Delorme & Makeig, 2004), ERPLAB version 5.0.0.0 (Lopez-Calderon & Luck, 2014), and custom Matlab code. The continuous EEG data were digitally filtered between .03 and 19.4 Hz with a zero-phase shift butterworth filter (12 dB/octave roll-off, DC offset removed prior to filtering) using ERPLAB. Pre- and post-stimulus EEG epochs were processed separately, albeit in identical processing streams. Epochs were extracted with a total duration of 2500 ms (from -500 ms to 2000 ms relative to the onset of the task cue or the study word). The epoched data were subjected to Independent Components Analysis (ICA) (Jung et al., 2000) to identify artifactual EEG components (e.g., blinks, eye movements, muscle, etc). Prior to ICA, the epochs were baseline corrected to the average voltage across the epoch to improve estimation of the ICA components (Groppe, Makeig, & Kutas, 2009), and epochs with non-stereotypical artifacts (e.g., due to a participant coughing) were rejected. Rejection of the entire data belonging to an electrode, when necessary, was conducted prior to ICA. Data from rejected electrodes were replaced using Spline interpolation after removal of artifactual ICA components.

The SASICA (Chaumon, Bishop, & Busch, 2015) and ADJUST (Mognon, Jovicich, Bruzzone, & Buiatti, 2011) software packages were used to aid with the identification of artifactual components, and the final determination as to whether to remove a component was made by the first author. After ICA artifact correction, the epoched EEG data were re-referenced to linked mastoids (recovering the FCz electrode) and baseline corrected to the average voltage of the 500 ms preceding the time-locked event (the task cue or the study word). Epochs were rejected for averaging if (1) voltage in the epoch exceeded ±100 μV, (2) baseline drift exceeded 40 μV (determined as the absolute difference in amplitude between the average amplitude of the first and last 250 ms of each epoch), (3) an artifact was present based on visual inspection by the first author, (4) participants failed to respond to or incorrectly responded (i.e,. used the incorrect hand) on the study judgment, or (5) a participant's reaction time (RT) was faster than 450 ms during the study phase or 650 ms during the test phase.

ERPs for each electrode site and event of interest (task cue and study word) were created by averaging all artifact-free epochs according to the subsequent memory judgment within each encoding condition (short vs. long). For the reasons discussed above (see Rationale for the Test Phase), we segregated trials into three subsequent memory bins: (1) trials receiving an R response in conjunction with a correct source judgment, (2) trials receiving an R response in conjunction with an incorrect or Don't Know source memory decision, along with trials receiving a subsequent K response, and (3) trials receiving a subsequent New response (i.e., forgotten, or inaccessible, study words). The above binning scheme was applied separately to the short and long encoding conditions, resulting in a total of six bins for each event of interest (task cue and study word). For several of the participants (7 young and 6 older), fewer than 15 artifact-

free trials were available for the forgotten condition. Therefore, this bin was excluded from the group analysis and will not be discussed further.

Experimental Design and Statistical Analyses

The design of the experiment consisted of one between-participant variable (Age Group) and two within-participant task variables (Encoding Condition and Memory). In addition, there was a within-participant electrode site factor for the ERP analysis (see ERP Analyses and Figure 2 for further details).

The statistical analyses were carried our using *R* software version 3.3.2 (R Core Team, 2016). ANOVAs were conducted using the functions *afex* package version 0.16-1 (Singmann, Bolker, Westfall, & Aust, 2016). The Greenhouse-Geisser procedure was used to correct the degrees of freedom for non-sphericity in the ANOVAs (Greenhouse & Geisser, 1959), and is reflected in the reported degrees of freedom. Effect size measures for results from the ANOVAs are reported as partial-η^2 (Cohen, 1988). Results were considered significant at $p < .05$.

Behavioral Group Analysis. The dependent variables of interest from the behavioral data included three estimates of memory performance derived from the test data, and the median reaction time (RT; in ms) to the judgment during the study phase. The three memory estimates included estimates of recollection and familiarity derived from the R/K/N responses and a measure of source memory accuracy derived from the source memory judgments following an R response. Estimates of recollection and familiarity were calculated (without regard for the source judgment accuracy) separately for each encoding condition using the independent R/K/N estimation procedure (Yonelinas & Jacoby, 1995). Recollection is computed with the following formula:

$$Recollection = R_{old} - R_{new}$$

R_{old} and R_{new} represent the proportion of R responses to old and new items, respectively. Familiarity estimates were derived from the following set of formulas:

$$F_{old} = \frac{K_{old}}{1 - R_{old}}$$

$$F_{new} = \frac{K_{new}}{1 - R_{new}}$$

$$Familiarity = F_{old} - F_{new}$$

In the above formulae, K_{old} and K_{new} represent the proportion of K responses to old and new items, respectively.

Source memory was computed using a single-high threshold model (Snodgrass & Corwin, 1988) and modified to account for the "guess" rate (e.g., Mattson et al., 2013). We refer to this measure as source pR. This index was computed for both the short and long conditions using the following formula:

$$source\ pR = \frac{Hit - .5 * [1 - DK]}{1 - .5 * [1 - DK]}$$

Hit and *DK* refer to the proportion of R responses accompanied by a correct source judgment or a Don't Know judgment on the source memory test, respectively. Each of the above three

measures were submitted to separate 2 (Age: young, old) X 2 (Encoding: short, long) mixed factorial ANOVAs.

For each participant, we computed median RTs for trials from the four bins of interest in the ERP analysis, and these values were subjected to a 2 (Age: young, old) X 2 (Encoding: short, long) X 2 (Memory: source correct, source incorrect) mixed factorial ANOVA.

ERP Group Analysis. The analysis of the ERP data focused on preSMEs (time-locked to the onset of the task cues) and SMEs (time-locked to the onset of the study words) in specific time windows, which will be discussed further below. In all time windows, ERP amplitude was computed as the mean voltage (in μV) in the time window of interest relative to the mean voltage in the 500 ms time window prior to the time-locked event (task cue or study word). Unless otherwise specified, the data submitted to the omnibus ANOVAs (see below) were not range normalized.

As discussed in the Introduction, preSMEs in young adults typically onset approximately one second after onset of the task cue and increase in magnitude until the onset of the study event (e.g., Otten et al., 2006). Three equal length time windows (500-1000 ms, 1000-1500 ms, and 1500-2000 ms) were used to examine preSMEs. We expected preSMEs, when they occurred, would be most prominent in the latter two time windows as these correspond to the one second interval before the onset of the study event. The earlier time window was included as a control with the expectation that no reliable preSMEs would be present.

SMEs elicited by study events typically show a sustained positive deflection for subsequent source correct relative to source incorrect trials that can onset as early as 300-600 ms post-stimulus (e.g., Cansino, Trejo-Morales, & Hernandez-Ramos, 2010). Therefore, we defined

three time windows to examine the SMEs elicited by the study words: 300-600 ms, 600-1500 ms, and 1500-2000 ms.

The data from each of the time windows described above were submitted to separate omnibus ANOVAs that included the between participant factor of Age (young, old), and the within participant factors of Memory (source correct, source incorrect), and Encoding Condition (short, long), along with three within-subject electrode site factors: anterior/posterior (AP) chain (Fp, F, C, P, O), laterality (medial, lateral), and hemisphere (left, right). The electrodes included in the analysis, and how they were assigned to the three electrode site factors, are depicted in Figure 2. Given our interest in examining subsequent memory effects, only significant effects from the omnibus ANOVAs that include the Memory factor are reported.

To foreshadow the results, significant effects from the omnibus ANOVAs either included interactions between Memory and Age, or between Memory, Age, and Encoding condition. Significant interactions involving Memory and Age were followed up with separate ANOVAs in each age group that included the factors Memory, AP Chain, Laterality, and Hemisphere (after collapsing the data across the two encoding conditions).

Interactions from the omnibus ANOVA involving Age, Memory, and Encoding condition were first followed up with separate Memory, Age, AP Chain, Laterality, and Hemisphere ANOVAs for each encoding condition. The ANOVAs were split across the Encoding factor rather than Age because our primary focus was on examining age differences in preSMEs and SMEs. Interactions in a given encoding condition (short or long) in the above-described ANOVAs involving Age and Memory were further decomposed with separate Memory, AP Chain, Laterality, and Hemisphere ANOVAs for the young and older samples.

Results

Neuropsychological Test Scores

The results from the various measures of the neuropsychological test battery are reported in Table 1. Like prior studies from our lab (de Chastelaine, Mattson, Wang, Donley, & Rugg, 2016; Wang, de Chastelaine, Minton, & Rugg, 2012), the general trend is that age was associated with (1) decreased memory performance on the CVLT-II and reasoning ability, (2) slower performance on measures of processing speed, and (3) intact word reading (e.g., WTAR).

Behavioral Performance

Test Performance. Table 2 (top panel) lists the proportions of test trials receiving *R* (separated by the accuracy of the source memory response), *K*, and *N* responses. The numeric trend is that, relative to young adults, older adults showed (1) a decrease in the overall proportion of R responses to studied items, (2) a decreased rate of R responses that attracted a correct (R+SC) or a "don't know" source memory decision (R+DK), and (3) an elevated rate of R responses associated with an incorrect source memory decision (R+SI). Although the overall rate of incorrect R responses to new items was relatively consistent across the two age groups, older adults were more likely to endorse a new item as coming from one of the encoding tasks relative to young adults. In addition to these trends, there were minimal numeric differences between the two age groups in the raw proportion of K responses given to old and new items.

Relevant to the ERP analyses reported below, age group differences in the relative proportion of trials contributing to the source incorrect bin would confound any group differences in the ERPs. This could occur, for example, if the source incorrect bin for older adults comprised a higher proportion of R+SI and R+DK trials than in younger adults. The data in Table 2 allay this concern, as the relative proportions of source incorrect trials (R+SI and

R+DK) and K trials, which comprised the source incorrect memory bin in the ERP analyses reported below, were similar across young and older adults and the two encoding conditions.

Regarding memory performance, prior research has typically demonstrated large age differences in recollection estimates accompanied by smaller, albeit significant age differences in familiarity estimates (particularly for estimates derived from the RK procedure, see Koen & Yonelinas, 2014; Schoemaker et al., 2014). The recollection and familiarity estimates derived from the R/K/N judgments in the present experiment replicated this pattern of results. Specifically, older adults showed large reductions in RK estimates of recollection, [$F(1,46) = 9.00$, $MS_e = 0.04$, $p = 0.004$, partial-$\eta^2 = 0.16$] and smaller, but still significant, age deficits in estimates of familiarity, [$F(1,46) = 4.36$, $MS_e = 0.05$, $p = 0.042$, partial-$\eta^2 = 0.09$] (see bottom panel of Table 2). There were no significant effects or interactions involving the Encoding factor, [all p's ≥ 0.240].

Regarding source memory, healthy older adults typically show large deficits in source memory relative to young adults (for review, see Old & Naveh-Benjamin, 2008; Spencer & Raz, 1995). Surprisingly, there were no significant effects involving Age (nor any significant effects of Encoding condition) on the source pR measure, [all p's ≥ 0.222]. A likely explanation for this null finding for the Age factor is that conditionalizing the source pR estimate on trials attracting R responses minimized age differences. We will return to this issue in the General Discussion.

Study RT. Table 3 shows the group averages of each participant's median reaction time (RT) during the study phase as a function of subsequent memory. The ANOVA on the median RTs did not reveal any effects that included Age, [all p's involving Age ≥ 0.177]. The absence of age effects suggests that any age differences in SMEs are unlikely to be attributable to group differences in RT. The ANOVA did however reveal two significant main effects. There was a

main effect of Memory, [$F(1,46) = 6.40$, $MS_e = 6847$, $p = 0.015$, partial-$\eta^2 = 0.12$], with slower RTs on trials in the source correct bin (M = 1247 ms, SE = 34 ms) relative to trials in the source incorrect bin (M = 1217 ms, SE = 33 ms). Additionally, there was a main effect of Encoding condition, [$F(1,46) =6.06$, $MS_e = 14592$, $p = 0.018$, partial-$\eta^2 = 0.12$], that was driven by faster RTs for study trials belonging to the long (M = 1210 ms, SE = 33 ms) than the short (M = 1253 ms, SE = 34 ms) condition. It is important to point out that the slower RTs in the short encoding condition are consistent with the assumption presented in the Introduction that limited perceptual availability increases task difficulty, and might increase incentive in engaging prestimulus processes.

Task-Cue ERPs

In this section, we report the results relevant to age differences in pre-stimulus subsequent memory effects (preSMEs) – differences in ERPs elicited by the task cue as a function of subsequent memory. The number of trials contributing to the ERPs time-locked to the task cue for young and old adults in each encoding condition are reported in the left half of Table 4. We reiterate that encoding trials that went on to be forgotten (i.e., trials that subsequently received an N response) were not included in the analysis due to an insufficient number of trials in a high number of participants (see EEG/ERP Analysis).

Figures 3 and 4 illustrate the grand average ERPs elicited by the task cues in young and older adults, respectively, for each encoding condition. Figure 5 plots ERP traces from a fronto-central virtual electrode for each age group and encoding condition. As was described in the ERP Group Analysis section of the Methods, the SME analyses focused on the average ERP amplitude in the 500-1000 ms, 1000-1500 ms and 1500-2000 ms time windows.

500-1000 ms. The omnibus ANOVA produced a significant four-way interaction between Memory, Age, AP Chain, and Laterality (see top panel of Table 5). A visual inspection of the 500-1000 ms time window (see Figure 6) indicates that older adults, but not young adults, show negative going (source correct < source incorrect) preSMEs in fronto-central electrodes in both the short and long encoding conditions. We decomposed the interaction from the omnibus ANOVA with separate follow up ANOVAs for each age group with the factors of Memory, AP Chain, Laterality, and Hemisphere (the data were first collapsed across the encoding condition). In older adults, there was a significant interaction between Memory and AP Chain, [$F(2.19,50.37) = 4.54$, $MS_e = 0.96$, $p = 0.013$, partial-$\eta^2 = 0.17$]. However, no significant effects involving the Memory factor were observed in young adults, [all p's involving Memory $\geq$ 0.124]. Thus, only older adults showed a reliable negative-going preSME in this time window.

1000-1500 ms. The omnibus ANOVA for the 1000-1500 ms time window produced three significant interactions involving a mixture of the Age, Memory, and Encoding, and electrode site factors (see middle panel of Table 5). Together, these interactions indicate that the preSMEs in the 1000-1500 ms time window differed by both age group and encoding condition. A visual inspection of the ERP data suggests that the driver of these interactions is a negative going preSME with a fronto-central distribution for the short encoding condition in young adults, but not older adults, with no corresponding preSME in the long encoding condition in either age group (see Figures 5 and 7).

To test whether there were age differences in preSMEs in each encoding condition, we first conducted separate Memory, Age, AP Chain, Laterality, and Hemisphere ANOVAs on the ERP amplitudes for each condition. The ANOVA for the short encoding condition produced a significant interaction involving Memory, Age, AP Chain, Laterality, and Hemisphere,

[$F(2.58,118.77) = 3.31$, $MS_e = 0.38$, $p = 0.028$, partial-$\eta^2 = 0.07$. The same ANOVA for the long encoding condition produced no effects of Memory or any interactions involving Age and Memory in the long encoding condition, [all p's involving Memory ≥ 0.15].

Importantly, specific to the short encoding condition, a further ANOVA with the factors Memory, AP Chain, Laterality, and Hemisphere in young adults produced a significant interaction involving Memory, AP Chain, and Laterality, [$F(2.72,62.60) = 3.79$, $MS_e = 0.43$, $p = 0.017$, partial-$\eta^2 = 0.14$], whereas the same ANOVA in older adults produced no effects involving Memory, [all p's involving Memory ≥ 0.16]. As is summarized in Figure 7, the results from the 1000-1500 ms time window demonstrated a detectable negative preSME in the short encoding condition only in young adults.

1500-2000 ms. The omnibus ANOVA on the preSMEs in the 1500-2000 ms time window produced two significant interactions involving a combination of the factors of Age, Memory, and Encoding Condition (see bottom panel of Table 5). These interactions indicate that the preSMEs in the 1500-2000 ms time window differed both by age group and encoding condition. Contrary to what was reported above for the 1000-1500 ms time window, a visual inspection of the data suggests that the pattern of results in this later time window are driven by larger age differences in the long encoding condition relative to the short encoding condition (see Figures 5 and 8). Specifically, the preSMEs appear to be positive-going for young adults in the long encoding condition but absent for older adults. Moreover, for young adults, the preSMEs in the short condition, while still negative-going, appear to be smaller relative to the 1000-1500 ms time window.

To decompose the above-mentioned interactions, we first conducted a follow-up ANOVA for each of the two encoding conditions that involved the factors of Memory, Age, AP

Chain, Laterality, and Hemisphere. The follow-up ANOVA in the short encoding condition produced no significant effects involving Memory, [all *p*'s involving Memory ≥ 0.086]. In contrast, there was a significant interaction involving Age and Memory in the long encoding condition, [$F(1,46) = 4.11$, $MS_e = 9.86$, $p = 0.048$, partial-$\eta^2 = 0.08$]. These results are consistent with the impression given by Figure 8 that age differences in preSMEs are largest in the long encoding condition for the 1500-2000 ms time window.

Importantly, in the long encoding condition only, an ANOVA with the factors of Memory, AP Chain, Laterality, and Hemisphere produced a significant effect of Memory in young adults, [$F(1,23) = 4.65$, $MS_e = 8.10$, $p = 0.042$, partial-$\eta^2 = 0.17$], whereas the same ANOVA in older adults produced no effects involving Memory, [all *p*'s involving Memory ≥ 0.234]. Together, as summarized in Figure 8B, the results from the 1500-2000 ms time window suggest that young adults showed a positive-going (source correct > source incorrect) preSME in the long encoding condition, whereas older adults did not show reliable preSMEs in either condition.

Summary. The analysis of the ERP data from the task cue epoch demonstrated clear age differences in preSMEs. In the time window typically reported to show preSMEs (the 1000-1500 ms and 1500-2000 ms time windows; approximately 1 second prior to onset of the study event), young adults showed reliable preSMEs in both the short and long encoding conditions. Critically, there were marked differences in the preSMEs for the two conditions. The preSME in the short encoding condition was negative (source correct < source incorrect) and was maximal in the 1000-1500 ms time window, whereas the effect in the long encoding condition was positive and maximal in the 1500-2000 ms time window. Although we failed to detect a preSME

in older adults in either of these time windows, they did demonstrate a preSME in the early (500-1000 ms) time window that was insensitive to the Encoding Condition factor.

Study Word ERPs

In this section, we report the results relevant to age differences in 'post-stimulus' subsequent memory effects (hereafter referred to as SMEs) – memory-related differences in ERPs elicited by the study words. The number of trials contributing to the ERPs time-locked to the study word for young and old adults in both encoding conditions are reported in the right half of Table 4. Figures 9 and 10 illustrate the grand average ERPs elicited by the study words in young and older adults, respectively, for each encoding condition. The analyses of the SMEs focused on the average ERP amplitude in the 300-600 ms, 600-1500 ms and 1500-2000 ms time windows.

300-600 ms. The were no significant effects involving the Memory factor in the omnibus ANOVA during the 300-600 ms time window, [all *p*'s involving Memory ≥ 0.073].

600-1500 ms. The omnibus ANOVA of SMEs in the 600-1500 ms time window produced interactions involving Memory, Age and the three electrode site factors (see middle panel of Table 6). Collectively, these interactions indicate that the SME differed between young and older adults. A visual inspection of the data indicates that younger adults showed a positive going SME in fronto-central electrodes whereas older adults showed a negative SME in the same electrodes (see Figure 11).

To examine whether SMEs were present in each age group, the young and older adult data (collapsed across encoding condition) were submitted to separate ANOVAs with the factors Memory, AP Chain, Laterality, and Hemisphere. The ANOVAs produced significant effects of Memory in both young and older adults. In young adults, there was an interaction involving

Memory, AP Chain, and Laterality, [$F(2.86,65.68) = 3.64$, $MS_e = 0.14$, $p = 0.019$, partial-$\eta^2 = 0.14$], which reflects a positive going SME at fronto-central electrodes that is not apparent in older adults (see Figure 11). In older adults, there was a significant interaction between Memory and Hemisphere [$F(1,23) = 4.46$, $MS_e = 0.24$, $p = 0.046$, partial-$\eta^2 = 0.16$] that appears to be driven by a negative going SME in left hemisphere electrodes.

Figure 12 plots the range-normalized SMEs for young and older adults (collapsed across the Encoding factor). Given the significant interactions described above involving Memory with at least one electrode site factor in both young and older adults, it is possible that there are age differences in the configurations of the neural generators of the observed SMEs. To address this issue, we first range normalized the SMEs (after collapsing across encoding condition), and then submitted the normalized values to an ANOVA with the factors Age, AP Chain, Laterality, and Hemisphere. If there are age differences in the configuration of the neural generators of the SMEs, then the ANOVA just described should reveal a significant interaction involving Age and at least one electrode site factor. However, the ANOVA did not produce any significant effects involving age, [all *p*'s involving Age ≥ 0.198], indicating that the scalp topographies of SMEs in young and older adults did not significantly differ from one another.

1500-2000 ms. The omnibus ANOVA for the SME in the 1500-2000 ms time window produced a significant four-way interaction between the Memory, Age, Encoding and Laterality factors (see bottom panel of Table 6). Figure 13 provides a visual depiction of the 4-way interaction. However, as will be discussed below, follow-up analyses failed to reveal the driver of the interaction.

A follow-up ANOVA in the long encoding condition with the factors Memory, Age, AP Chain, Laterality, and Hemisphere produced no effects involving Memory, [all *p*'s involving

Memory ≥ 0.213], whereas an identical ANOVA in the short encoding condition produced a significant interaction between Age, Memory, and Laterality, [$F(1,23) = 4.46$, $MS_e = 0.24$, $p = 0.046$, partial-$\eta^2 = 0.16$]. Within the short encoding condition, however, neither age group showed significant SMEs. Specifically, a further Memory, AP Chain, Laterality, and Hemisphere ANOVA on the short encoding condition produced no significant effects involving memory in either young adults, [all *p*'s involving Memory ≥ 0.293], or older adults, [all *p*'s involving Memory ≥ 0.051].

Summary. The ERPs elicited by the study words produced reliable SMEs, regardless of the encoding condition, primarily in the 600-1500 ms time window. There were age differences in this effect that appear to be driven by a larger positive SME (source correct > source incorrect) at fronto-central electrodes in young adults compared to older adults. However, older adults also showed reliable SMEs in the same time window that were likely a result of a more negative SME in left (primarily posterior) electrodes. A topographic analysis failed to detect age differences between young and older adults in the scalp topography of the SMEs.

Discussion

The present study examined age differences in preparatory processes as indexed by the presence of ERP prestimulus subsequent memory effects (preSMEs) (Otten et al., 2006). We examined preSMEs across two encoding conditions that were assumed to differentially benefit from preparatory processing. Young, but not older, adults showed reliable preSMEs in both the short and long encoding conditions. In addition, we observed a relatively early, short-lived preSME in older adults that did not significantly vary between the two encoding conditions. Taken together, the results suggest that young and older adults differ in their ability to engage preparatory processes during memory encoding.

Behavioral Results

Consistent with quantitative reviews of the literature (see Koen & Yonelinas, 2014; Schoemaker et al., 2014), estimates of both recollection and familiarity derived from the RK judgments were lower in older adults relative to younger adults. Importantly, age differences were larger for estimates of recollection relative to estimates of familiarity. However, there were no reliable age differences in source memory (i.e., memory for the encoding task). This was unexpected given the extensive literature showing large age differences in source memory (Old and Naveh-Benjamin, 2008; Spencer and Raz, 1995), and particularly so in light of findings showing larger age-related deficits in source memory relative to recollection estimates derived from R/K/N judgments (Duarte et al., 2008).

Why did the older adults fail to show reduced source accuracy, despite the presence of significantly reduced estimates of recollection derived from the R/K/N procedure? The most parsimonious account of this null finding is that source memory judgments were limited to trials already endorsed with an R response. Thus, participants may have constrained their R responses to those trials for which they were confident they could recollect the source detail (i.e., the encoding task) (cf., Parks, 2007). By this account, the lack of an age difference in source memory accuracy coupled with significant age differences in R/K/N estimates of recollection simply reflects the fact that older adults were less likely to recall source details than young participants. If this account is accurate, then our findings are consistent with the literature on age differences in source memory performance. However, additional research is needed to confirm the validity of this account.

Prestimulus Subsequent Memory Effects in Young Adults

The critical finding in young adults' ERPs concerns the different pattern of preSMEs in the two encoding conditions. The "standard" preSME in prior research is a negative going deflection for subsequently recollected versus non-recollected study events that is maximal at fronto-central electrodes in the second immediately preceding onset of the study word (Galli et al., 2012; 2013; Gruber & Otten, 2010; Otten et al., 2006; 2010). In the short encoding condition, the preSMEs in young adults exhibited this standard pattern – there was a negative deflection for source correct trials relative to source incorrect trials, and the deflection was maximal in the 1000-1500 ms time window following onset of the task cue. However, this finding was not present in the long encoding condition, where we observed a polarity-reversed preSME. This effect was maximal at mid-frontal electrodes in the 1500-2000 ms time window. To our knowledge, ERP preSMEs taking this form have not been reported previously, and we have no ready explanation for this finding. Analogous findings are not wholly unprecedented however: using fMRI, de Chastelaine and Rugg (2015) recently reported a cross-over interaction in the direction of preSMEs in the hippocampus as a function of whether the cued study task engaged semantic or phonological processing.

An important aspect of the preSMEs observed in young adults concerns the different polarity preSMEs between the short and long encoding conditions. This dissociation likely reflects the greater incentive for preparatory processing that accompanied the short condition (see Introduction). Admittedly, this explanation does not account for the reversed polarity preSME observed in the long encoding condition (assuming it is a replicable effect). Notably, though, the stimulus durations employed in prior ERP studies of preSMEs with visual stimuli (Galli et al., 2012; Galli et al., 2013; Gruber & Otten, 2010; Otten et al., 2006; Otten et al., 2010) in no case exceeded 500ms, raising the possibility that standard preSMEs (see above) are

confined to circumstances where the study presentation places a high premium on prestimulus preparation. Future research is needed to identify the boundary conditions of when preSMEs in ERPs will and will not be observed.

Age Differences in Prestimulus Subsequent Memory Effects

Unlike in young adults, we were unable to detect standard preSMEs in older adults. This finding is in line with our hypothesis that preSMEs in older adults would be reduced in comparison to those demonstrated by young adults. The lack of detectable standard preSMEs in older adults is consistent with other research indicating that older adults have a reduced capacity to engage in preparatory (i.e., proactive) processes (Braver et al., 2009; Duverne et al., 2009; Morcom & Rugg, 2004). Reliable preSMEs were however observed in older adults in an earlier time window. Although the functional significance of these 'non-standard' preSMEs in older adults is currently obscure, this finding does not negate the broader conclusion that there are age differences in preSMEs that reflect differences in the engagement of prestimulus preparatory processing.

Post-stimulus Subsequent Memory Effects

The SMEs evident in the young adults replicated several previous reports (see Introduction). Specifically, these SMEs were positive-going, frontally-distributed and did not reliably vary between the encoding conditions. By contrast, SMEs in older participants were markedly attenuated and, if anything, polarity-reversed. These age differences are consistent with prior research (e.g., Friedman & Trott, 2000; Mark & Rugg, 1998) and are consistent with the hypothesis that aging leads to reduced efficacy of encoding processes that support successful recollection (for reviews, see Craik & Rose, 2012; Friedman et al., 2007).

What might account for the age differences in SMEs observed here and in prior reports? The extensive literature on the effects of age on SMEs expressed in fMRI BOLD activity offers some intriguing clues. SMEs in fMRI studies take one of two forms (for review, see Kim, 2011; Rugg et al., 2015): 'positive' SMEs, when BOLD activity is greater for later remembered than forgotten items, and 'negative' SMEs, when BOLD activity is greater for later forgotten items. It has been reported in numerous studies that semantically elaborative study tasks are associated with SMEs predictive of later recollection in several cortical regions (most notably, lateral prefrontal cortex), as well as the medial temporal lobe, including the hippocampus. Negative SMEs, by contrast, are typically localized to regions of the 'default mode network'. The balance of the evidence indicates that positive SMEs differ little, if at all, as a function of age (indeed, some effects are *larger* in older adults) (e.g., de Chastelaine et al., 2016; de Chastelaine, Wang, Minton, Muftuler, & Rugg, 2011), while negative SMEs are consistently reported to be attenuated, or even reversed, in older adults (de Chastelaine, Mattson, Wang, Donley, & Rugg, 2015; Mattson et al., 2013). Viewing the present (and previous, Friedman et al., 2007) findings of age-related reductions in ERP SMEs through the lens of this fMRI evidence, it is tempting to speculate that these SMEs are reflections of the same neural processes responsible for negative SMEs in fMRI data. Future research directly comparing ERP and fMRI data in the same samples of participants will be needed to address this possibility.

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Table 1.

Demographic and neuropsychological test data for young and older adults.

	Young	Old
N	24	24
Sex (M/F)	11/13	11/13
Age[1]	23.50 (18 – 30)	69.42 (64 – 75)
Education[1]	16.25 (12 – 20)	17.33 (13 – 24)
MMSE	29.54	29.21
CVLT SD – Free	13.17 (1.76)	10.75 (3.38)
CVLT SD – Cued	13.75 (1.70)	11.83 (2.78)
CVLT LD – Free	13.83 (1.76)	11.13 (3.33)
CVLT LD – Cued	14.17 (1.49)	11.88 (3.00)
CVLT Recognition – Hits	15.50 (0.78)	14.88 (1.42)
CVLT Recognition – False Alarms	0.54 (0.66)	2.13 (2.35)
SDMT	61.17 (12.67)	51.04 (7.97)
Digit Span (Total)	21.54 (3.82)	18.96 (3.18)
Trails A (secs)	21.96 (8.64)	26.93 (8.68)
Trails B (secs)	52.07 (21.46)	65.22 (21.58)
FAS (Total)	44.54 (9.35)	45.54 (8.33)
Category Fluency (Animals)	22.71 (4.91)	20.71 (5.84)
WTAR (Raw)	40.58 (3.24)	43.46 (4.12)
Logical Memory I	30.29 (4.32)	28.63 (6.50)
Logical Memory II	27.71 (5.20)	25.08 (6.75)
Raven's (List 1)	11.00 (1.06)	8.83 (2.04)

Note. Unless otherwise specified, standard deviations are provided in parentheses along with the

means. [1]Range is reported in parentheses.

Table 2.

Means (and standard errors) for the proportion of trials in each response category, and the mnemonic process estimates derived from the R/K/N and Source memory judgments at test.

	Young Adults			Older Adults		
	Short	Long	New	Short	Long	New
Response Category						
R+SC	0.43 (0.03)	0.42 (0.03)	-	0.36 (0.03)	0.36 (0.02)	-
R+SI	0.06 (0.02)	0.06 (0.01)	0.05 (0.02)	0.11 (0.01)	0.11 (0.01)	0.09 (0.02)
R+DK	0.13 (0.02)	0.14 (0.02)	0.05 (0.01)	0.05 (0.01)	0.05 (0.01)	0.02 (0.01)
K	0.20 (0.02)	0.21 (0.02)	0.21 (0.03)	0.22 (0.02)	0.23 (0.03)	0.21 (0.03)
N	0.17 (0.02)	0.17 (0.02)	0.69 (0.04)	0.26 (0.02)	0.21 (0.03)	0.68 (0.04)
Estimates of Mnemonic Processes						
Recollection (RK)	0.53 (0.03)	0.52 (0.03)		0.40 (0.03)	0.40 (0.03)	
Familiarity (RK)	0.30 (0.04)	0.31 (0.03)		0.20 (0.03)	0.22 (0.03)	
Source Accuracy (pR)	0.51 (0.04)	0.48 (0.05)		0.45 (0.05)	0.47 (0.04)	

Note. It is impossible to have a source correct response for new items, thus there is no value for the R+SC response category for new items. The R+SI cell for the new items reflects the proportion of trials in which participants incorrectly selected an encoding task on the source memory judgment. Specifically, the Source Correct bin comprised R+SC trials, whereas the Source Incorrect bin included R+SI, R+DK, and K trials.

R+SC: Remember + Source Correct response

R+SI: Remember + Source Incorrect response

R+DK: Remember + Source Don’t Know response

K: Know response

N: New response

Table 3.

Mean (and standard errors) for the average median reaction time (RT) to judgments made during the study phase.

	Young Adults		Older Adults	
	Short	Long	Short	Long
Source Correct	1257 (74)	1185 (73)	1289 (69)	1229 (63)
Source Incorrect	1237 (72)	1177 (73)	1256 (59)	1223 (60)

Note. The bins for the RTs were comprised of the same trials as the ERP bins.

Table 4.

Mean (and range) of the number of trials contributing to the bins for the task cue ERPs and word elicited ERPs as a function of age, encoding condition, and subsequent memory.

		Task Cue ERPs		**Study Word ERPs**	
Age	Encoding Condition	Source Correct	Source Incorrect	Source Correct	Source Incorrect
Young	Short	49 (21-81)	45 (28-73)	48 (21-83)	46 (28-76)
	Long	47 (22-80)	47 (31-76)	49 (22-82)	45 (29-73)
Old	Short	42 (23-69)	45 (20-80)	42 (24-72)	46 (16-76)
	Long	42 (24-72)	46 (16-76)	43 (23-68)	44 (21-81)

Note. The mean number of trials was rounded down to the nearest whole number.

Table 5.

Results from the omnibus ANOVA for each time window in the task cue epoch.

Model Term	*df*	*F*	MS_e	*p*	η_p^2
500-1000 ms					
Memory X Age X AP X Laterality	2.82,129.82	3.53	0.27	0.019	0.07
1000-1500 ms					
Memory X Age X Encoding X AP Chain	1.87,85.93	4.43	2.99	0.017	0.09
Memory X Encoding X Laterality	1,46	4.79	0.48	0.034	0.09
Memory X Encoding X AP Chain X Hemisphere X Laterality	3.32,152.59	2.70	0.10	0.042	0.06
1500-2000 ms					
Memory X Age X Encoding	1,46	6.32	7.03	0.016	0.12
Memory X Age X Encoding X Laterality	1,46	4.82	0.54	0.033	0.09

Note. Only significant effects involving the Memory factor are reported. Reported degrees of freedom (*df*) are Greenhouse-Geisser corrected.

Table 6.

Results from the omnibus ANOVA for each time window in the study word epoch.

Model Term	*df*	*F*	MS_e	*p*	η_p^2
300-600 ms					
No significant effects involving Memory					
600-1500 ms					
Memory X AP Chain	1.71,78.47	4.09	4.61	0.026	0.08
Memory X Hemisphere	1,46	4.65	1.00	0.036	0.09
Memory X Age X AP Chain X Laterality	2.73,125.56	3.23	0.31	0.029	0.07
1500-2000 ms					
Memory X Age X Encoding X Laterality	1,46	4.31	1.02	0.043	0.09

Note. Only significant effects involving the Memory factor are reported. Reported degrees of freedom (*df*) are Greenhouse-Geisser corrected.

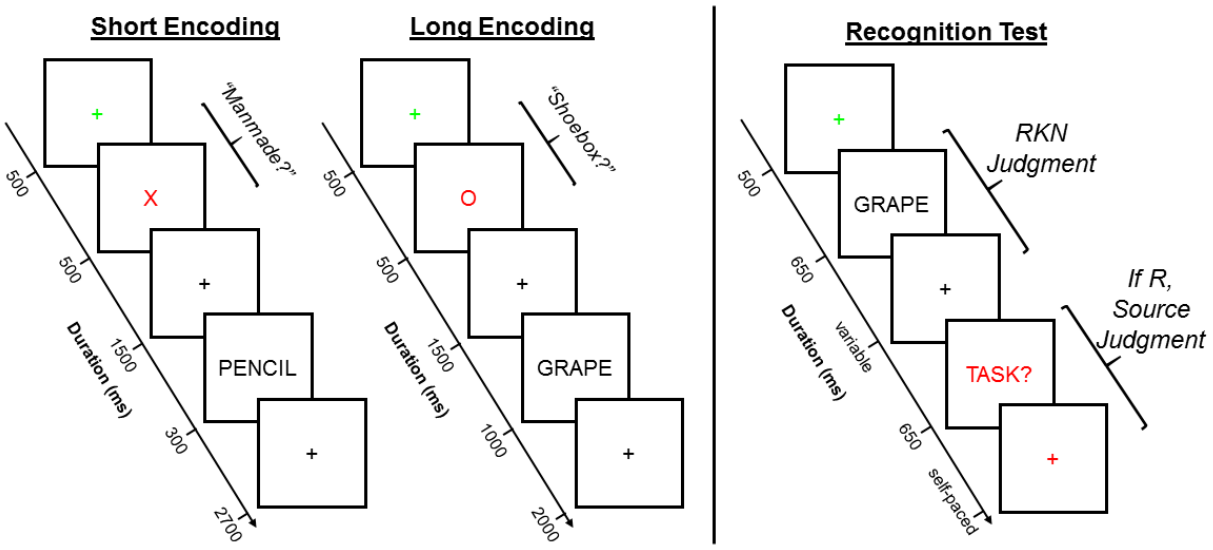

Figure 1. Visual depiction of the experimental memory task. During the study phase, participants were presented with a list of words and asked to make one of two possible judgments about each word. Prior to the presentation of each word, participants were presented with a task cue, specifically a red 'X' or 'O', that instructed participants to make either the Manmade or Shoebox judgment, respectively, about the following word. There were two blocked encoding conditions (short and long) that varied in the amount of time the word appeared on the screen, and participants were informed in advance of the duration of the word. Importantly, the amount of time participants had to respond did not differ between the two encoding conditions. At test, participants were shown words from the study phase intermixed with new words. Participants first made an old/new decision using Remember, Know, and New judgments and, when a Remember response was given, participants were asked to retrieve the judgment they made about the word during the study phase. The response alternatives for this latter judgment included the label of the two encoding tasks (Manmade and Shoebox) as well as a Don't Know response option. Participants were not informed about the subsequent test prior to the study phase, and thus encoding was incidental. EEG was recorded during both the study and test phases.

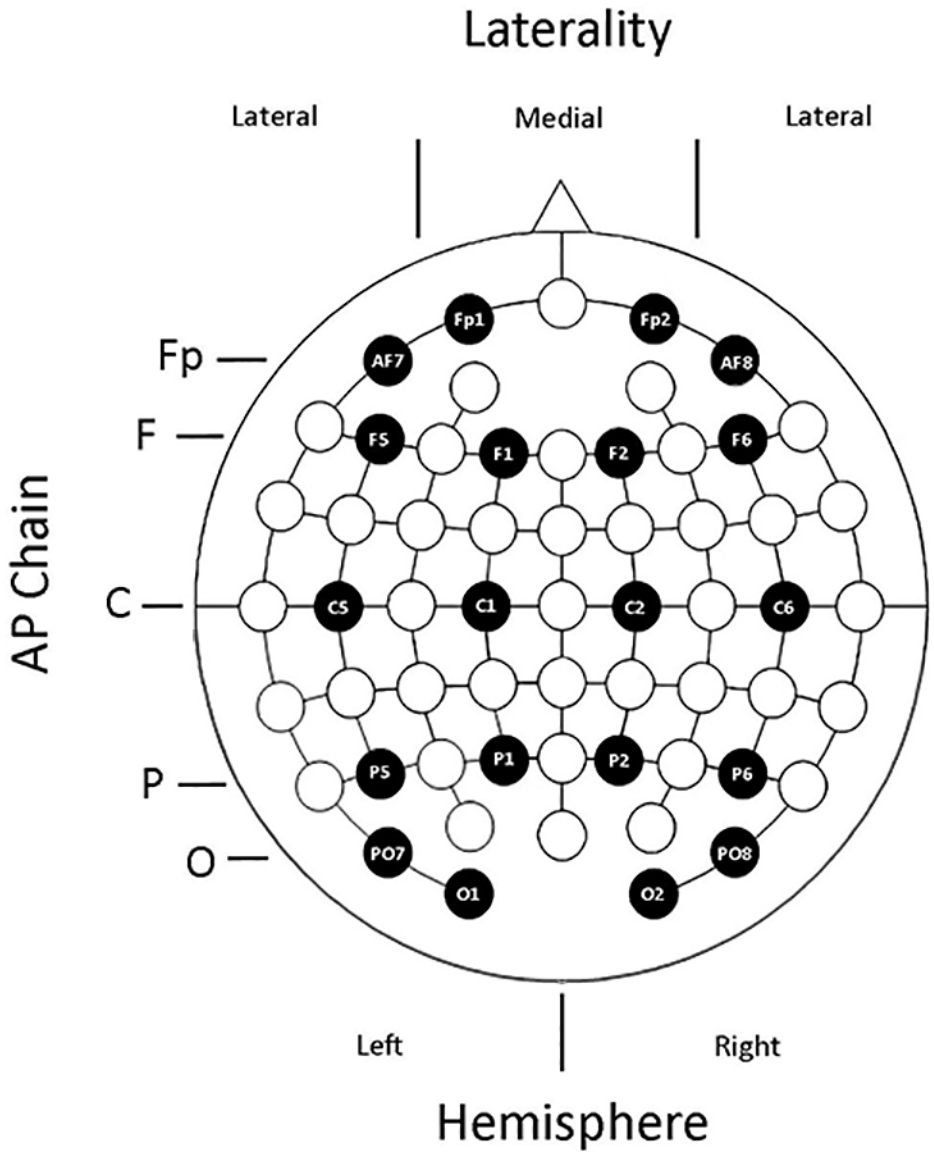

Figure 2. Visual depiction of the electrodes and the anterior-posterior chain (AP Chain), Laterality, and Hemisphere electrode factors used in the ERP omnibus ANOVAs.

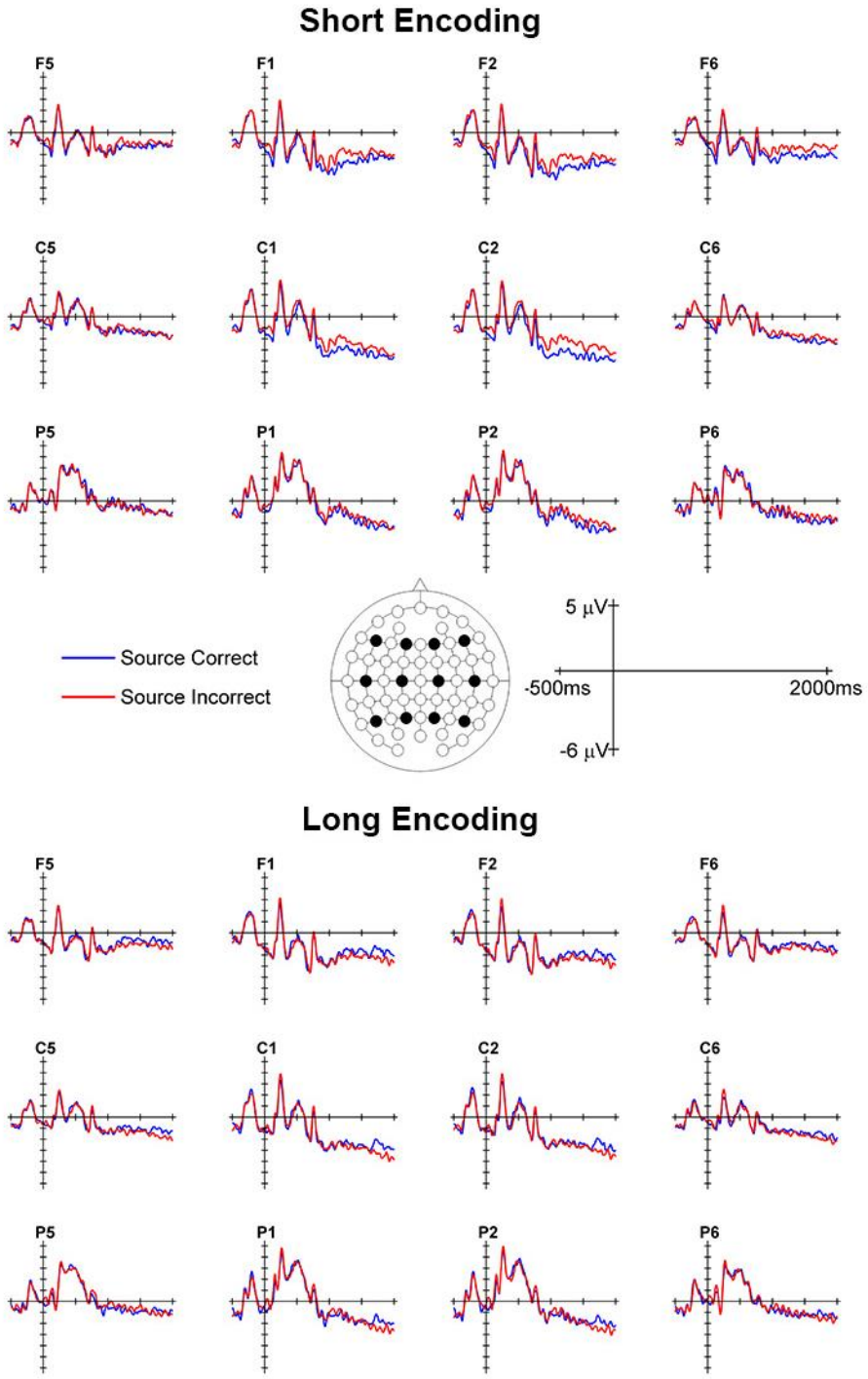

Figure 3. Grand average ERPs of the task cue epoch for the short (top panel) and long (bottom panel) encoding condition in young adults. Each tick mark on the *y*-axis represents 1 µV, and each tick mark on the *x*-axis represents 500 ms.

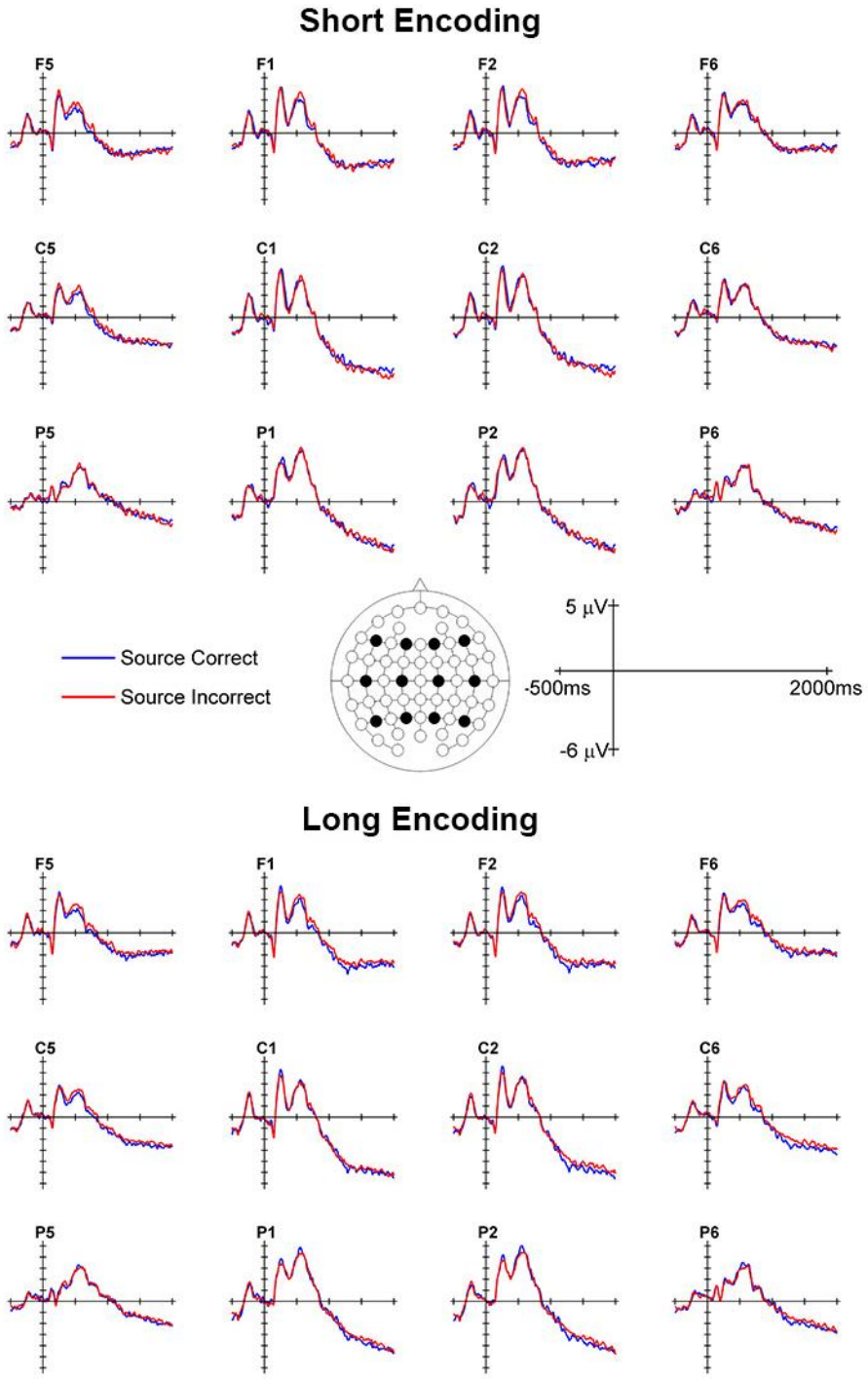

Figure 4. Grand average ERPs of the task cue epoch for the short (top panel) and long (bottom panel) encoding condition in older adults. Each tick mark on the *y*-axis represents 1 µV, and each tick mark on the *x*-axis represents 500 ms.

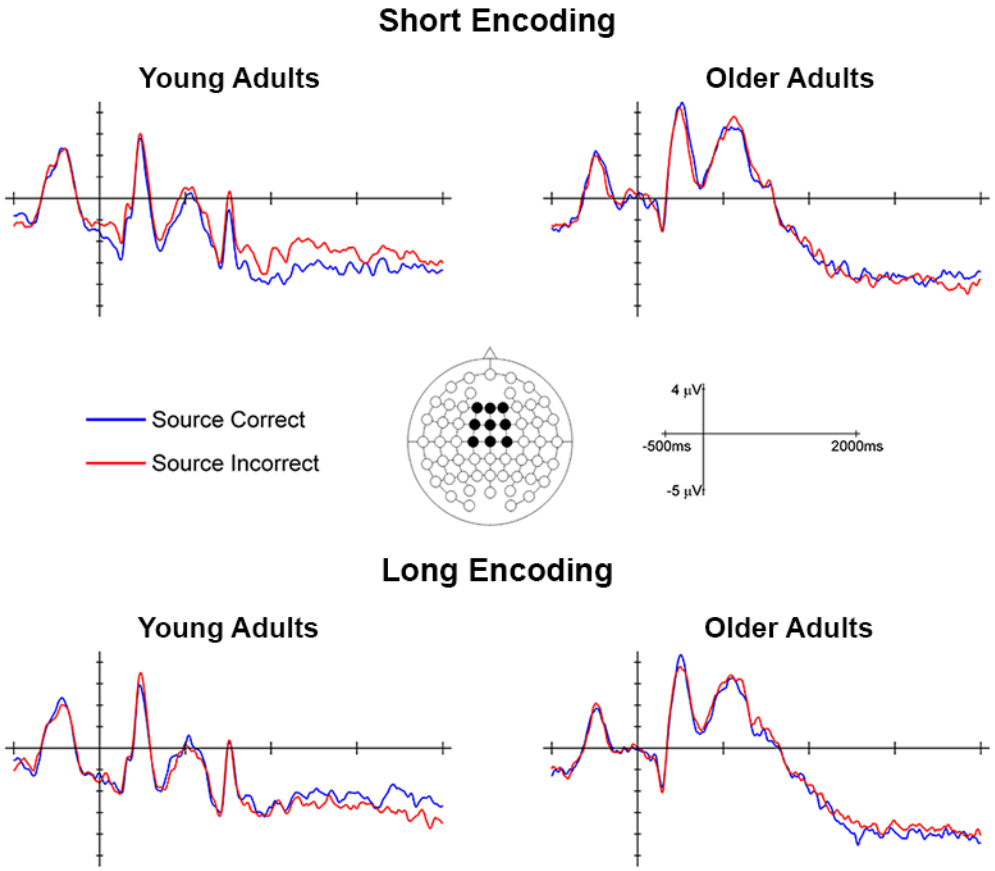

Figure 5. ERP grand average traces from a virtual electrode for the short and long encoding conditions in both age groups for task cue epoch examining preSMEs. The virtual electrode was created by averaging across electrodes F1, F2, Fz, FC1, FC2, FCz, C1, C2, and Cz.

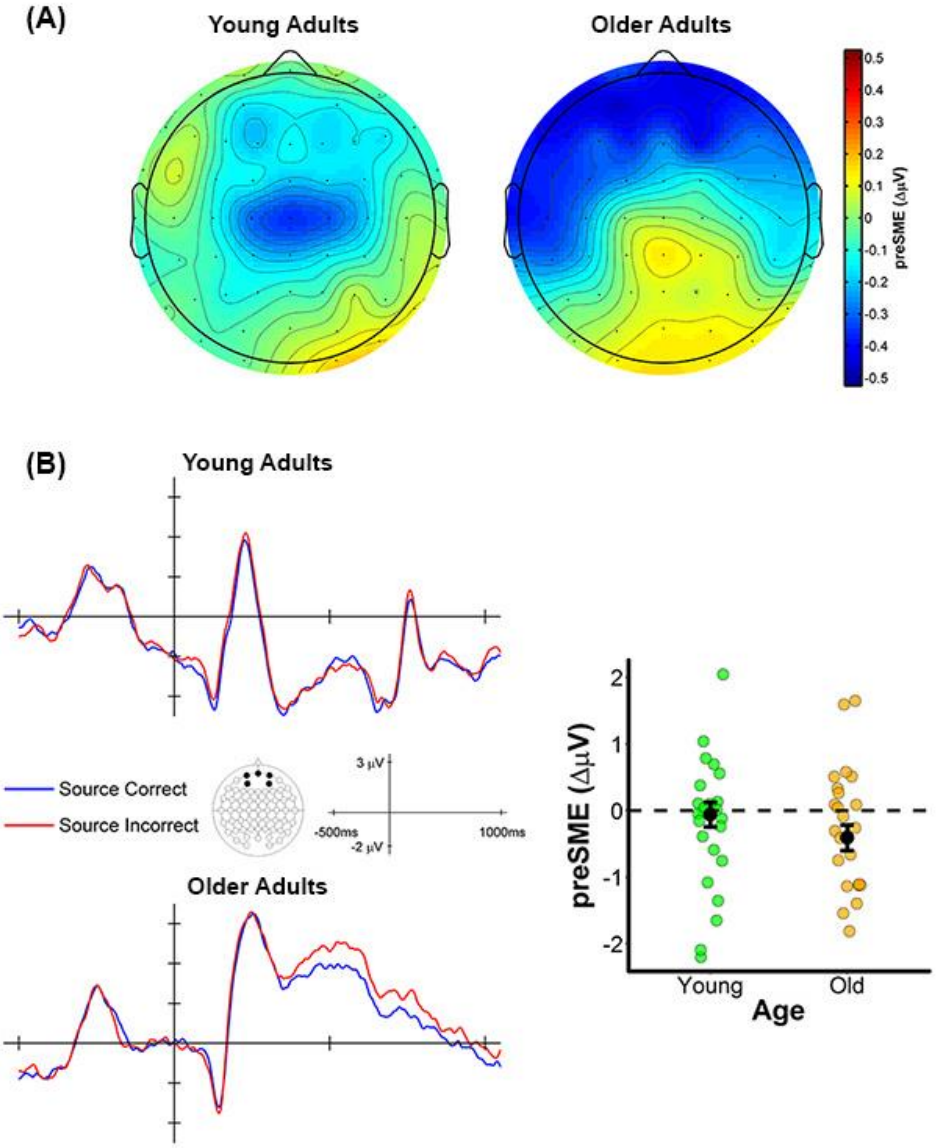

Figure 6. (A) Scalp plot of the preSMEs (source correct – source incorrect) in young and older adults in the 500-1000 ms time window following onset of the task cue (collapsed across encoding condition). Note the common scale used to depict the magnitude of the preSMEs in each age group. (B) ERP grand average traces (left) and a plot of the mean preSMEs (right) from a virtual electrode created by averaging across Fp1, Fp2, Fpz, AF3, and AF7. The ERP trace only shows up to the 1000 ms following the onset of the task cue. The green and orange points represent the preSMEs in individual participants, and the black point (with error bars of ±1 standard error of the mean) reflects the mean of each age group.

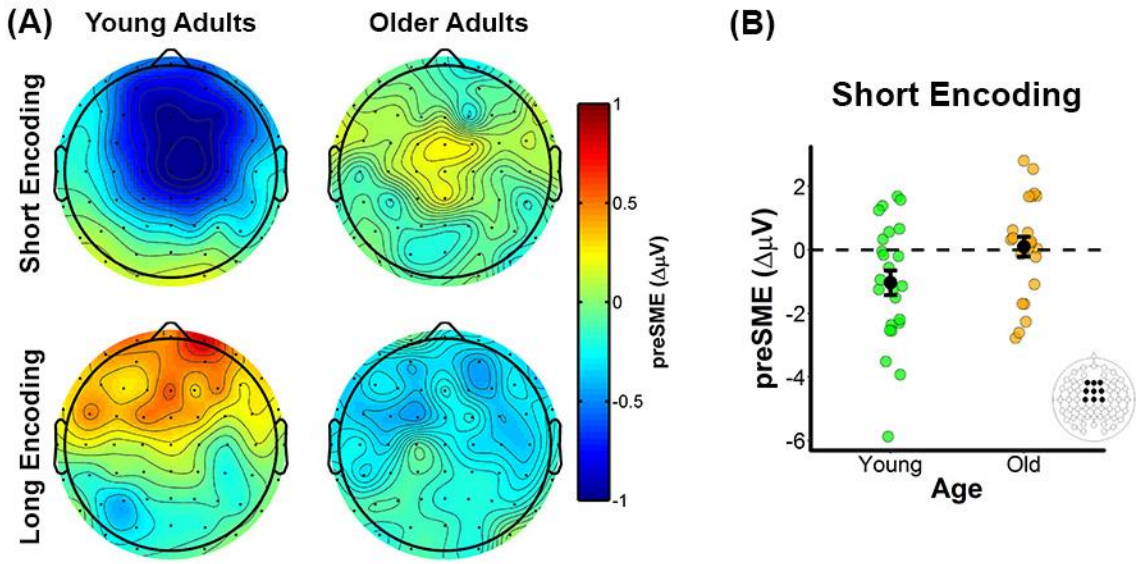

Figure 7. (A) Scalp plot of the preSMEs (source correct – source incorrect) in young and older adults in the 1000-1500 ms time window following onset of the task cue. Note the common scale used to depict the magnitude of the preSMEs in each age group and encoding condition. (B) Plot of the mean preSMEs averaged across fronto-central electrodes highlighted on the inset (C1, Cz, C2, F1, Fz, F2, FC1, FCz, FC2). The green and orange points represent the preSMEs in individual participants, and the black point (with error bars of ±1 standard error of the mean) reflects the mean of each age group.

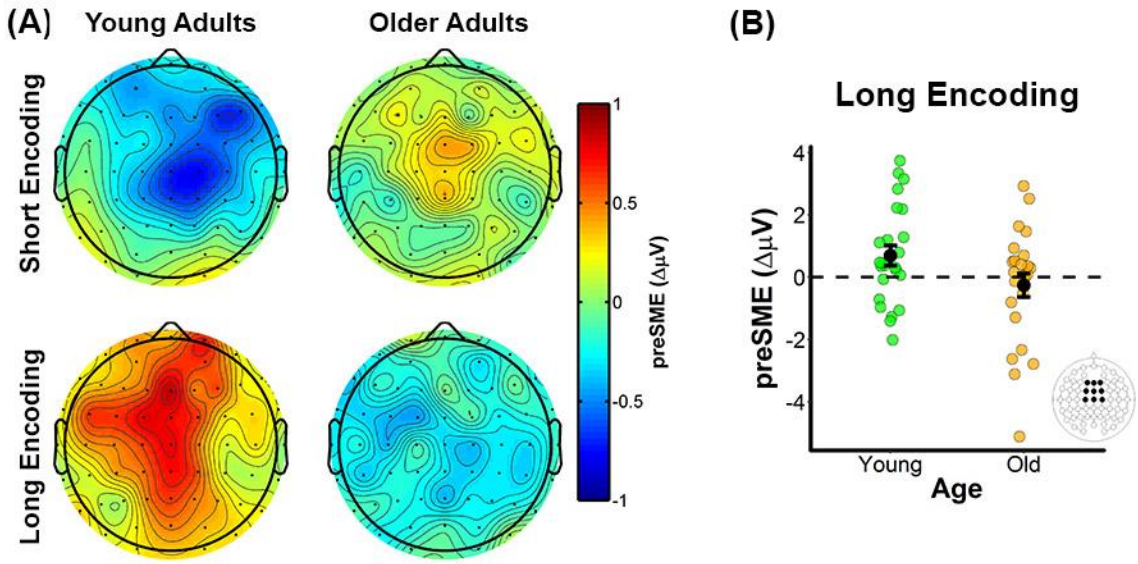

Figure 8. (A) Scalp plot of the preSMEs (source correct – source incorrect) in young and older adults in the 1500-2000 ms time window following onset of the task cue. Note the common scale used to depict the magnitude of the preSMEs in each age group and encoding condition. (B) Plot of the mean preSMEs averaged across fronto-central electrodes highlighted on the inset (C1, Cz, C2, F1, Fz, F2, FC1, FCz, FC2). The green and orange points represent the preSMEs in individual participants, and the black point (with error bars of ±1 standard error of the mean) reflects the mean of each age group.

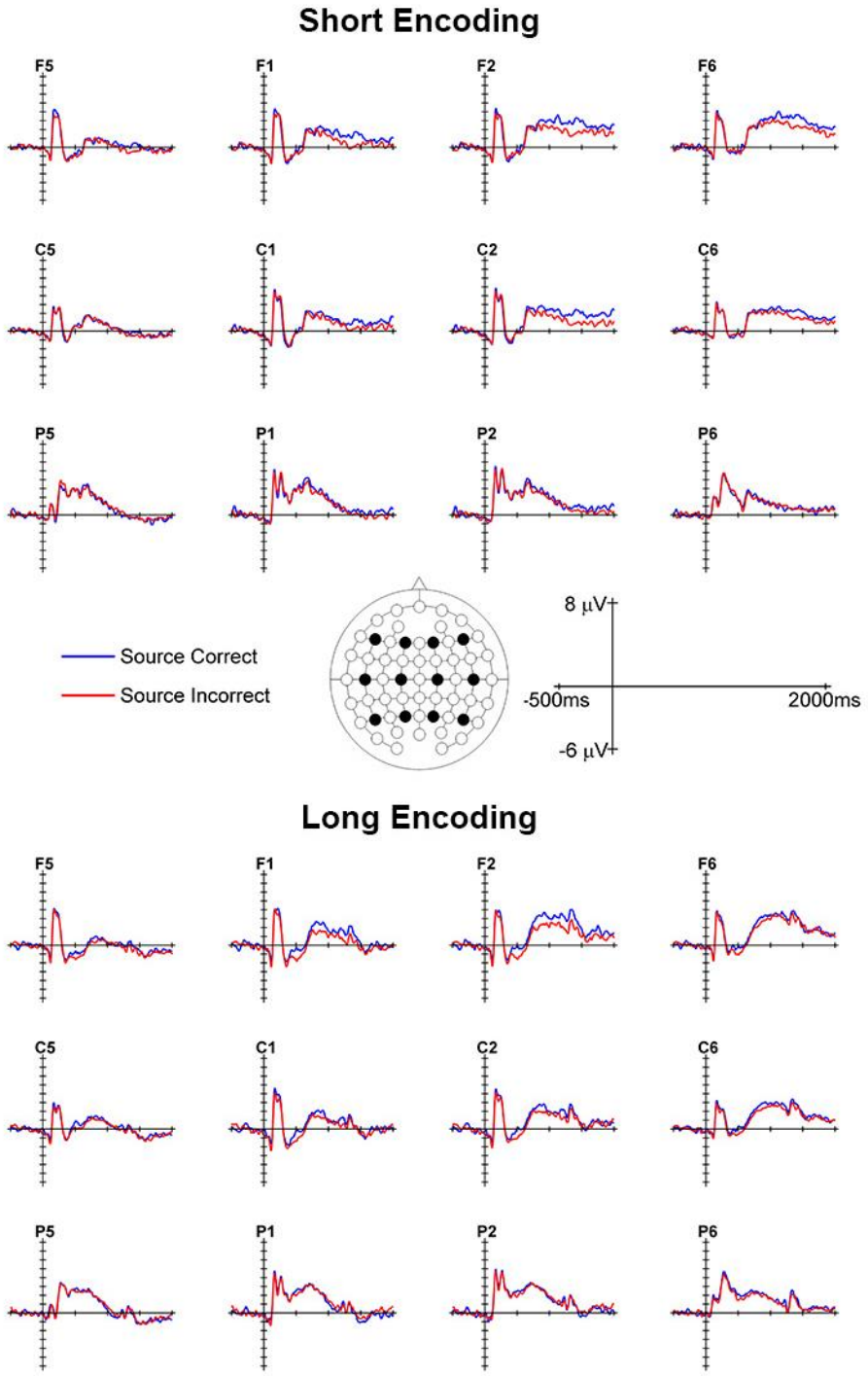

Figure 9. Grand average ERPs of the study word epoch for the short (top panel) and long (bottom panel) encoding condition in young adults. Each tick mark on the *y*-axis represents 1 μV, and each tick mark on the *x*-axis represents 500 ms.

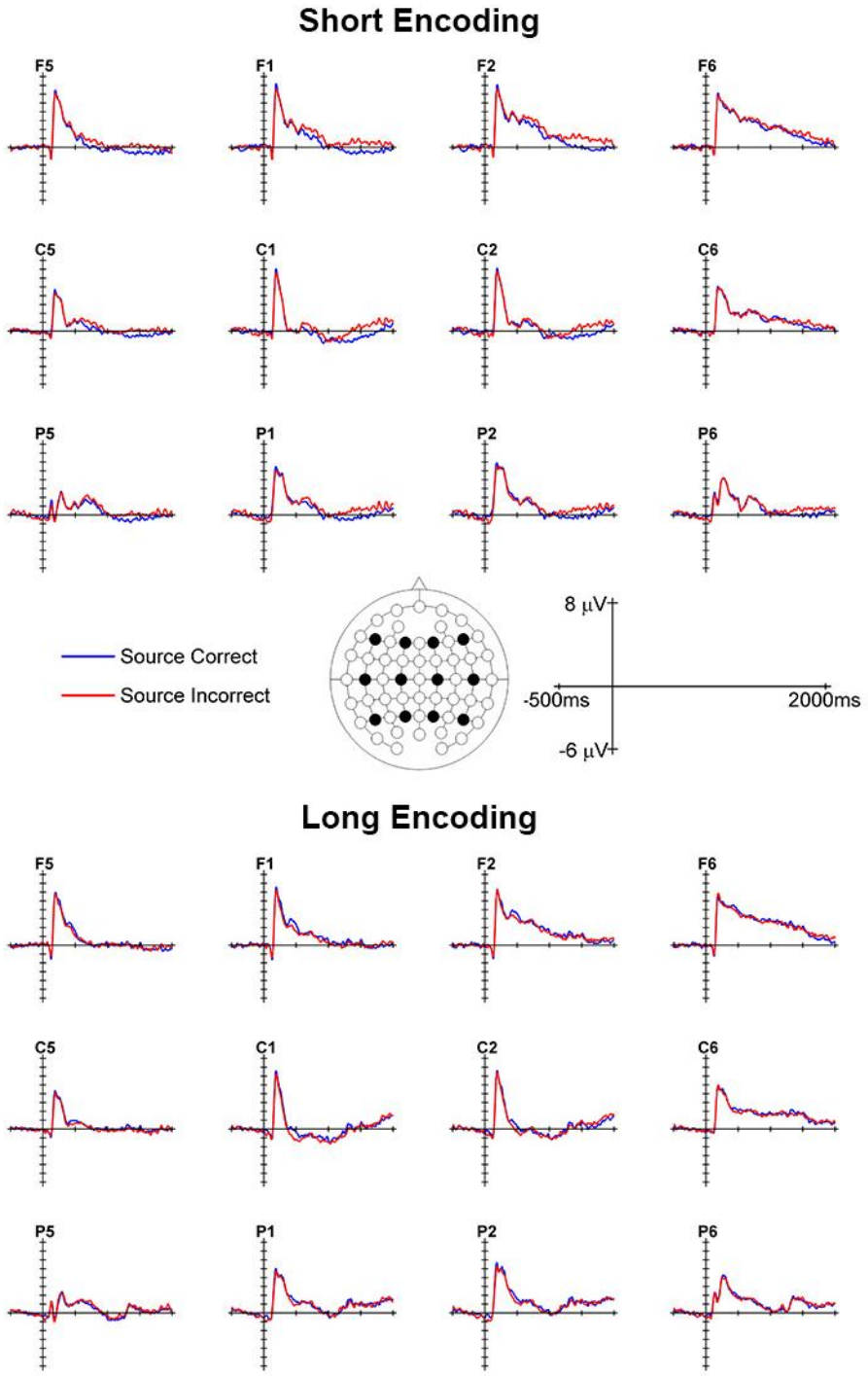

Figure 10. Grand average ERPs of the study word epoch for the short (top panel) and long (bottom panel) encoding condition in older adults. Each tick mark on the *y*-axis represents 1 μV, and each tick mark on the *x*-axis represents 500 ms.

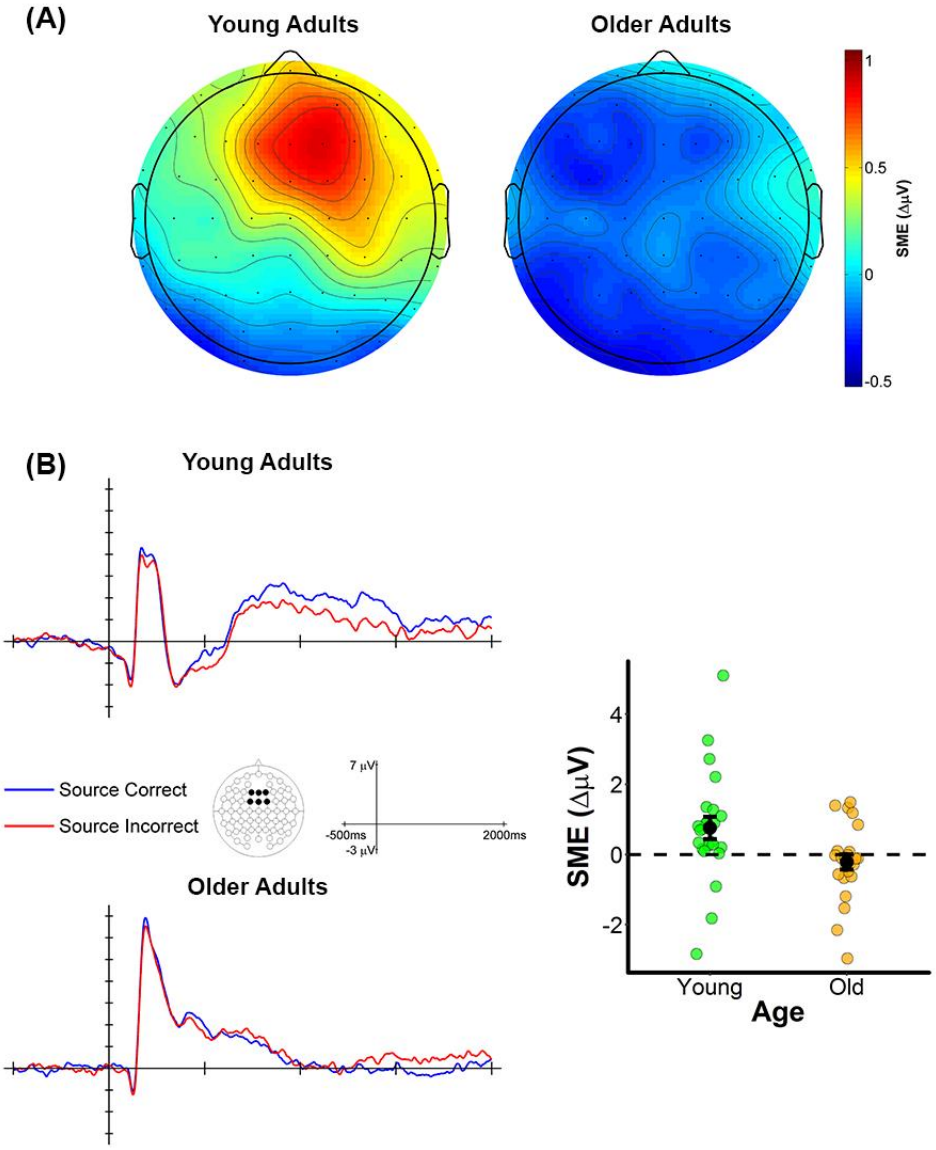

Figure 11. (A) Scalp plot of the SMEs (source correct – source incorrect) in young and older adults in the 600-1500 ms time window following onset of the study word (collapsed across encoding condition). Note the common scale used to depict the magnitude of the SMEs in each age group and encoding condition. (B) Plot of the mean SME averaged across fronto-central electrodes highlighted on the inset (F1, Fz, F2, FC1, FCz, FC2). The green and orange points represent the SME in individual participants, and the black point (with error bars of ±1 standard error of the mean) reflects the mean of each age group.

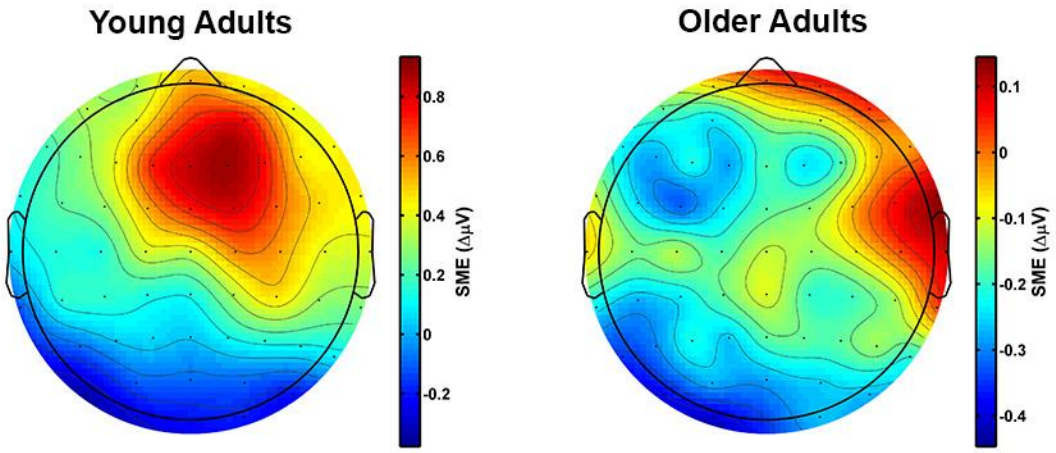

Figure 12. Topography of the SMEs (source correct – source incorrect) in the 600-1500 ms time window following onset of the study words (collapsed across encoding condition). Unlike the scalp map presented in Figure 11A, the scalp maps in this figure are min-max scaled separately for young (left) and older (right) adults to show the topography of the effect. Although there was a significant Memory by electrode factor interaction in each age group, there were no reliable differences in the topography of the SMEs between young and older adults as indicated by an ANOVA on range-normalized data.

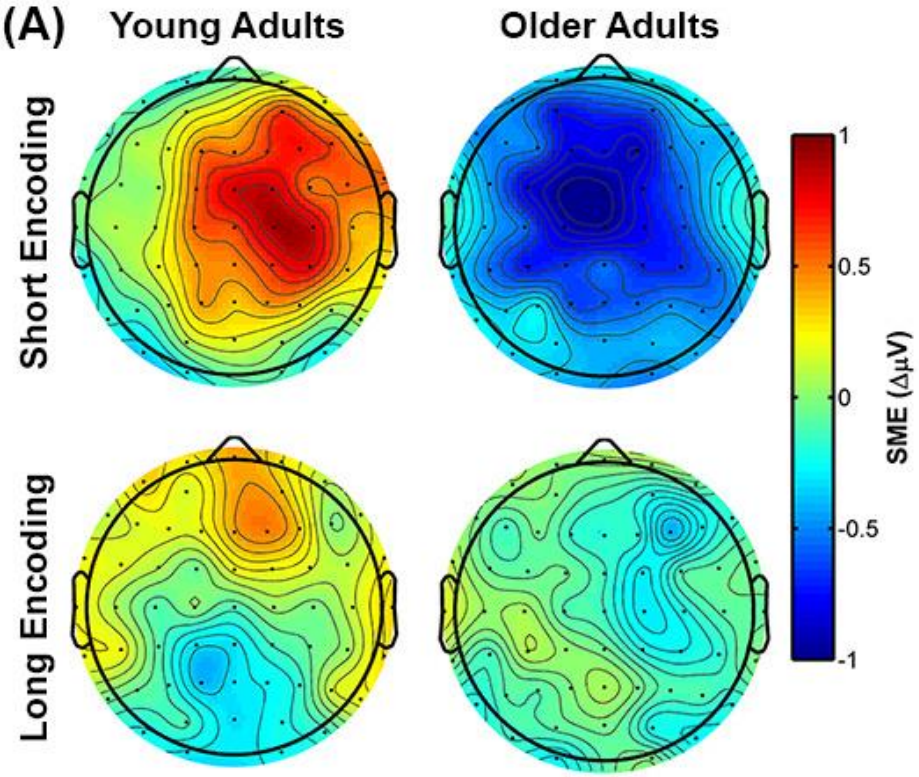

Figure 13. Scalp plot of the SMEs (source correct – source incorrect) in young and older adults in the 1500-2000 ms time window following onset of the study word. Note the common scale used to depict the magnitude of the SME in each age group and encoding condition. The omnibus ANOVA showed a reliable interaction between Memory, Age, and Encoding condition (that also involved electrode factors) that appeared to be driven by differing polarities of the SMEs between young and older adults in the short encoding condition. However, post-hoc analyses did not show any reliable Memory effects in any of the four scalp plots depicted.