The effects of aging on emotion-induced modulations of source retrieval
ERPs: Evidence for valence biases

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ABSTRACT

Many behavioral studies have shown that memory is enhanced for emotionally salient events across the lifespan. It has been suggested that this mnemonic boost may be observed for both age groups, particularly the old, in part because emotional information is retrieved with less effort than neutral information. Neuroimaging evidence suggests that inefficient retrieval processing (temporally delayed and attenuated) may contribute to age-related impairments in episodic memory for neutral events. It is not entirely clear whether emotional salience may reduce these age-related changes in neural activity associated with episodic retrieval for neutral events. Here, we investigated these ideas using event-related potentials (ERPs) to assess the neural correlates of successful source memory retrieval (“old–new effects”) for neutral and emotional (negative and positive) images. Behavioral results showed that older adults demonstrated source memory impairments compared to the young but that both groups showed reduced source memory accuracy for negative compared to positive and neutral images; most likely due to an arousal-induced memory tradeoff for the negative images, which were subjectively more arousing than both positive and neutral images. ERP results showed that early onsetting old–new effects, between 100 and 300 ms, were observed for emotional but not neutral images in both age groups. Interestingly, these early effects were observed for negative items in the young and for positive items in the old. These ERP findings offer support for the idea that emotional events may be retrieved more automatically than neutral events across the lifespan. Furthermore, we suggest that very early retrieval mechanisms, possibly perceptual priming or familiarity, may underlie the negativity and positivity effects sometimes observed in the young and old, respectively, for various behavioral measures of attention and memory.

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1. Introduction

Numerous studies have suggested that item memory is enhanced for emotionally salient events compared to neutral events in healthy young and older adults (Buchanan & Adolphs, 2002; Cahill & McGaugh, 1998; Denburg, Buchanan, Tranel, & Adolphs, 2003; Hamann, 2001; Otani, Libkuman, Widner, & Graves, 2007). Emotionally- arousing events draw attentional focus consequently increasing the likelihood that these events will be encoded. Some-what less clear is how source memory or memory for experimentally-manipulated episodic associations (i.e., “source” features, such as spatial location, temporal order, color, etc.) is affected by emotion in the young and old. Results from existing source memory studies of emotion are mixed. For example, source memory accuracy has been shown to be reduced (Mather et al., 2006) or equivalent (Kensinger & Schacter, 2006a; Koenig & Mecklinger, 2008) for emotional and neutral images. The inverse relationship between memory for emotional items and that for neutral event details has been described as an emotion-induced memory “tradeoff” in which enhanced attention toward the emotional items comes at the cost of encoding neutral peripheral contextual features like background scenes (Kensinger, Gutchess, & Schacter, 2007; Reisberg & Heuer, 2004). Of course there are many kinds of episodic associations and some may be more easily integrated or intrinsic to the items than others. For example, some evidence from the young suggests that if the source details are intra-item features, such as word font color or the modality of presentation (i.e., whether the item was seen or imagined) source memory is enhanced for negative compared to neutral items (Doeksen & Shimamura, 2001; Kensinger & Corkin, 2003; Kensinger & Schacter, 2006b, 2007; Mather, Gorlick, & Nesmith, 2009; Mather & Nesmith, 2008) and positive arousing compared to neutral items (Mather et al., 2009; Mather & Nesmith, 2008). Indeed, a few studies have shown...
that young and older adults are more likely to remember specific visual details about previously presented negative pictures than positive or neutral pictures (Kensinger, Garoff-Eaton, & Schacter, 2007) and are more able to correctly determine whether they had seen or merely imaged a negative compared to a positive or neutral object (Kensinger, O’Brien, Swanberg, Garoff-Eaton, & Schacter, 2007). It is important to note that the source details assessed in these aging studies by Kensinger and colleagues might be considered intrinsic to the items. Collectively, these studies suggest that source memory accuracy may benefit, in both the young and the old, when the events are emotionally salient and the source features are easily integrated with the items.

One potential explanation for the emotion-induced enhancement in episodic memory in both groups, particularly the old, may relate to the manner in which emotional memories are retrieved. It has been suggested that emotional information may be retrieved with relatively “less effort” than neutral information (Clark-Foos & Marsh, 2008; Zajonc, 1980). Source retrieval places demands on effortful control processes like post-retrieval monitoring (Dobbins & Han, 2006; Fletcher & Henson, 2001; Simons & Spiers, 2003) and inhibition of irrelevant information (Badre & Wagner, 2007; Johnson, Hashtroudi, & Lindsay, 1993 for reviews). Healthy aging is believed to be associated with declines in these and other executive processes (Hasher & Zacks, 1979; Light, 1991), which likely contributes to the age-related memory impairments often observed for a variety of source details (e.g., perceptual, conceptual, spatial, temporal) and kinds of stimuli (words, objects, faces) (Mitchell & Treese, 2004; Langeslag & van Strien, 2008; Schaefer, Pottage, & Rickart, 2010; Weymar, Low, Melzio, & Hamm, 2009) and positive (Langeslag & Van Strien, 2008; Weymar et al., 2009) compared to neutral stimuli, although a few have shown no differences between valence categories (Van Strien, Langeslag, Strekalova, Gootjes, & Franken, 2009; Windmann & Kutas, 2001). Furthermore, consistent with the idea that automatic memory processes can contribute to recognition of emotional events, early onsetting frontal maximal old–new effects peaking at approximately 200 ms and sometimes implicated in familiarity (Duarte, Ranganath, Trujillo, & Knight, 2006; Duarte, Ranganath, Winward, Hayward, & Knight, 2004) were larger for negative than neutral (Schaefer et al., 2010) or positive (Van Strien et al., 2009) images in the young.

To our knowledge, no study has investigated how aging affects the emotion-induced modulations of ERPs during episodic retrieval (i.e., source, context, memory). Thus, it is unclear whether the age-related attenuations and onset delays often observed during source retrieval of neutral events (Duarte et al., 2006; Mark & Rugg, 1998; Swick, Senkfor, & Van Petten, 2006; Trott, Friedman, Ritter, & Fabiani, 1997; Trott, Friedman, Ritter, Fabiani, & Snodgrass, 1999; Wegesin, Friedman, Varughese, & Stern, 2002) would be equally observed for emotional events. For example, if young and older adults exhibit enhanced source memory accuracy for emotional compared to neutral events (Kensinger et al., 2007; Kensinger et al., 2007), the parietal old–new effect may be enhanced for both groups. If as described above, emotional information is retrieved with relatively “less effort” than is neutral information (Clark-Foos & Marsh, 2008; Zajonc, 1980) early onsetting old–new effects may be particularly evident for source retrieval of emotional events in both the young and the old.

One important factor that should be considered in studies of emotion and aging is the differential effect of valence on memory in the young and old. Behavioral evidence suggests that older adults are more likely to attend to and remember positive information while young adults typically show greater attention to and memory for negative information (reviewed in Mather & Carstensen (2005)). Taking this “positivity effect” at face value, one might predict that while young adults would show enhanced source memory accuracy for emotionally-salient pictures could enhance source memory performance for the young and old, and whether the commonly observed age-related changes in old–new ERPs, including attenuation and onset delays, are reduced for retrieval of emotional relative to neutral events. During study, participants made one of two semantic decisions (“indoor?” or “common?”) about negative, positive and neutral pictures. During test, studied and unstudied pictures were presented and participants judged which items they had seen previously and decided in which semantic context (source) the picture was initially presented.

We predicted that:

(1) Emotion-induced source memory impairments should be minimal and source recognition for the semantic context may even
be greater for emotional than for neutral images in both young and older adults. As described earlier, many of the previous studies that have demonstrated tradeoff effects for arousing emotional stimuli assessed memory for what might be considered low priority peripheral or extra-item information including spatial location and background scenes (Denburg et al., 2003; Kensinger, Pignat, Krendl, & Corkin, 2005; Mather et al., 2006; Waring & Kensinger, 2009). By contrast, memory for stimulus-specific visual details (Doerksen & Shimamura, 2001; Kensinger & Corkin, 2003; Kensinger et al., 2007) and mode of presentation (seen or imagined) (Kensinger et al., 2007; Kensinger et al., 2006b, 2007; Kensinger & Schacter, 2006a) has been shown to be greater for emotional than neutral items. There are a few reasons why we believe that the neutral semantic encoding context falls into the category of source features more easily integrated/intrinsic to items than peripheral features subject to arousal-induced tradeoffs. In a previous study by Kensinger and Schacter, (2006a), source recognition was equivalent (i.e., no tradeoff effect) for emotional (negative and positive) and neutral pictures and words when the sought after source was the semantic encoding context (common/anxiety oriented tasks. Second, the semantic context used in the present study is neutral and intended to minimize attention to the arousing elements of the images and consequently reduce an item-source tradeoff effect, which may be evident when the orienting task directs attention to emotional elements (Waring & Kensinger, 2009). Finally, we also acknowledge that that the semantic judgment associated with the images is relevant to the task goals in the current design and might be considered high priority and likely to benefit from arousal, consistent with arousal-biased competition theory (Mather & Sutherland, 2011).

2. Materials and methods

2.1. Participants

16 young adults (ages 19–36) were recruited from Georgia Institute of Technology, as well as from the metropolitan Atlanta community, and 14 older adults (ages 61–73) were recruited from the community. Additional participants (4 young and 6 old) were excluded due to poor performance, excessive eye movements or other EEG artifacts (e.g., alpha). All participants were right-handed, with normal or corrected to normal vision, with no reports of psychiatric or neurological disorders, vascular disease, or psychoactive drug use. None of the participants were taking CNS-active medications. All participants were paid $10 per hour for their time, or in the case of some of the young adults, given extra credit in a psychology class. All participants signed consent forms approved by the Georgia Institute of Technology Institutional Review Board. The total session duration, including time for consent forms, EEG setup and removal, experimental and neuropsychological testing was approximately 2.5–3 h. Group characteristics are displayed in Table 1.

2.2. Neuropsychological testing

Immediately following EEG recording, all participants were administered a neuropsychological test battery. This battery assessed immediate and long-term verbal and visuospatial memory, verbal fluency, working memory, and executive function and was administered to ensure no large group differences in performance due to cognitive impairment, such as preclinical dementia in the older group. The neuropsychological battery consisted of tests from the Memory Assessment Scale: digit span forward and backward, word list learning, recognition, immediate and delayed recall, as well as object recognition, reproduction, and delayed recognition (Williams, 1991). The trail making test A & B (Reitan & Wolfson, 1985) and the controlled oral word association task (Benton, Hamsher, & Sivan, 1983) were also given. This battery lasted approximately 20–30 min.

2.3. Stimuli

Given evidence showing that older adults compared to the young tend to rate emotional images as more extreme for both valence and arousal, especially for negative images (Gruhn & Scheibe, 2008), it is important to select stimuli for which subjective ratings are matched between age groups. To this end, we conducted a pilot study prior to the experiment in which we asked groups of 10 young and 10 older adults to rate emotional stimuli on 5-point scales of valence and arousal. These participants had similar demographics to the participants included in the experiment. A similar method has been used by Kensinger et al. (2007), Kensinger and Schacter (2007), Waring and Kensinger (2005), Lang, Bradley, & Cuthbert (2007), and Kensinger et al. (2005). Four hundred thirty two images from the International Affective Picture Set (IAPS) (Lang, Bradley, & Cuthbert, 1995) and 450 images from Google, divided evenly between valence categories as determined by the experimenters, were selected for rating. The neutral IAPS images tend to be depictions of objects while emotional images tend to portray complex scenes. Thus, an effort was made to select complex neutral images in order to avoid confusing image complexity with valence. No erotic images were used. Please see Supplemental methods for a description of the rating procedure.

We selected stimuli that had been rated as negative and arousing (arousal greater than 3.3 and valence greater than 3.8), positive and arousing (arousal greater than 3.3 and valence less than 2.2) and neutral and non-arousing (arousal less than 3.3 and valence between 2.3 and 3.7). However, we were unable to obtain a sufficient number of stimuli rated as both positive and arousing in either age group. Therefore we adjusted our lower cutoff for arousal ratings to 2.3 for positive and negative items and our upper cutoff for neutral items to 2.2. Thus, we decided to prioritize selecting stimuli for each category for which there were no group differences in valence ratings [t's < 1.3, p's > 0.18]. Both groups rated negative items as more arousing than both positive [t's > 33.48, p's < 0.001] and neutral items [t's > 58.44, p's < 0.001], and positive items as more arousing than

Table 1

<table>
<thead>
<tr>
<th>Measure</th>
<th>Young (n = 16)</th>
<th>Old (n = 14)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age 25.0 (5.2)</td>
<td>67.7 (4.6)</td>
<td></td>
</tr>
<tr>
<td>Gender 8 female</td>
<td>5 female</td>
<td></td>
</tr>
<tr>
<td>Education 16.0 (2.10)</td>
<td>15.8 (1.98)</td>
<td></td>
</tr>
<tr>
<td>Letter fluency 48.75 (12.24)</td>
<td>49.78 (12.87)</td>
<td></td>
</tr>
<tr>
<td>Immediate list free recall 10.81 (1.28)</td>
<td>10.50 (1.28)</td>
<td></td>
</tr>
<tr>
<td>Immediate list cued recall 10.68 (1.49)</td>
<td>11.21 (0.80)</td>
<td></td>
</tr>
<tr>
<td>Delayed list free recall 11.56 (0.63)</td>
<td>11.15 (1.06)</td>
<td></td>
</tr>
<tr>
<td>Delayed list cued recall 11.44 (0.81)</td>
<td>11.57 (0.64)</td>
<td></td>
</tr>
<tr>
<td>List recognition 11.81 (0.75)</td>
<td>11.81 (0.75)</td>
<td></td>
</tr>
<tr>
<td>Trails A 24.71 (11.02)</td>
<td>31.01 (7.12)</td>
<td></td>
</tr>
<tr>
<td>Trails B 54.08 (26.71)</td>
<td>85.05 (77.72)</td>
<td></td>
</tr>
<tr>
<td>Verb al span forward 6.87 (1.45)</td>
<td>7.35 (1.54)</td>
<td></td>
</tr>
<tr>
<td>Visual reproduction 5.44 (1.31)</td>
<td>5.47 (1.97)</td>
<td></td>
</tr>
<tr>
<td>Immediate visual recognition 18.81 (1.38)</td>
<td>16.92 (2.52)*</td>
<td></td>
</tr>
<tr>
<td>Delayed visual recognition 19.38 (0.89)</td>
<td>17.92 (1.43)*</td>
<td></td>
</tr>
</tbody>
</table>

Note: Standard deviations in parentheses. All neuropsychological tests are reported as raw scores.

* Significant differences between groups at p < 0.05 for two-tailed T-tests.
neutral items [t's > 19.70, p's < 0.001]. For all three valences, older adults reported images as being more arousing than did younger adults [t's > 5.25, p's < 0.001]. See Table 2 for the mean valence and arousal ratings for each stimulus category and age group for the stimuli used in the current study. One hundred forty stimuli for each of the three valence categories were included. Stimuli for each valence were counterbalanced across old and new categories such that across all the participants, each stimulus was categorized both as an old and as a new item.

2.4. Design and procedure

Each stimulus was centrally presented and displayed at a maximum vertical and horizontal visual angle of up to 7° on a computer screen. Participants were provided with a short practice block of the study portion of the experiment immediately prior to the study phase and a short practice block of the test portion immediately prior to the test phase. The experimental practice and study and test blocks lasted approximately 1 h. There were four blocks of study followed by four blocks of test. EEG was recorded during test.

A schematic of the design is shown in Fig. 1. Each of the four study blocks contained 69 images: 23 negative, 23 positive, and 23 neutral. For each study trial, participants answered one of two questions about the image. For half the trials, they were asked to decide whether the image was common (i.e., something you might see within a typical month), and for the other half of the trials, they decided whether the image was indoors. Participants used the index finger of each hand to indicate their “yes” or “no” response on a Gravis Gamepad Pro and the mapping of hand to response was counterbalanced across subjects. The presentation of trials was pseudorandomized such that no more than 4 trials for either task (common/indoor) or valence were presented in a row. These tasks were meant to encourage incidental encoding of the item and provide a context that could subsequently be assessed during the source memory judgment at test.

Immediately following study, participants performed the test phase. Each of the four test blocks contained 69 studied and 36 unstudied images with equal proportions of each valence, presented in a pseudo-random order such that no more than 4 trials of any valence or type (studied/unstudied) were presented in a row. If more than 4 trials of any valence or type were presented in a row, the last one of that valence was presented as the first trial of the next block. For all four blocks, the items were presented in a pseudo-random order such that no more than 4 trials of any valence or type were presented in a row. For all three valences, images were matched for percentage of each valence category within the 27 studied and unstudied items for each valence category to ensure that the ratio of studied to unstudied items was the same for each participant. Participants were informed of the old/new ratio, similar to our study, manipulation of the old/new ratio had no effect on memory accuracy or any of the ERP effects of interest in the present study (Herron, Quayle, & Rugg, 2003).

![Table 2](#)

<table>
<thead>
<tr>
<th>Image type</th>
<th>Young (Mean, SD)</th>
<th>Old (Mean, SD)</th>
<th>Neutral (Mean, SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative</td>
<td>4.25 (0.29)</td>
<td>4.22 (0.31)</td>
<td>3.65 (0.23)</td>
</tr>
<tr>
<td>Positive</td>
<td>1.69 (0.27)</td>
<td>1.59 (0.37)</td>
<td>2.50 (0.21)</td>
</tr>
<tr>
<td>Neutral</td>
<td>2.74 (0.41)</td>
<td>2.77 (1.23)</td>
<td>2.12 (0.21)</td>
</tr>
</tbody>
</table>

Mean valence and arousal ratings as determined by pilot investigation for stimuli used in the experiment.

Table 2 Mean arousal and valence ratings as determined by pilot investigation for stimuli used in the experiment.

Note: Standard deviations in parentheses. Ratings made on a 5-point scale for both valence and arousal.

2.5. EEG acquisition

Scalp-recorded EEG data was collected from 32 Ag–AgCl electrodes using an ActiveTwo amplifier system (Biosemi, Amsterdam, Netherlands). Two additional electrodes placed on the left and right mastoid processes were used as off-line references. Four additional electrodes were placed above and below the left eye to record vertical electrooculogram (VEOG) and on the outer canthi of the left and right eyes to record horizontal electrooculogram (HEOG). EEG was recorded with a 24 bit resolution and a sampling rate of 512 Hz. All channels were off-line digitally band-pass filtered between 40 and 0.1 Hz. One bad electrode, Pz, was removed from all subsequent analyses for all participants. Prior to segmentation, eye movements were removed from the data using a method based on principal component analysis, similar to the method described by Berg and Scherg (1994) as available in EMSE version 5.3 (Source Signal Imaging). Extensive analysis of this method determined that there was no reduction in waveform magnitude. Epochs containing any uncorrected artifacts (≥100 μV) were removed. EEG segments were created from 200 ms pre-stimulus onset, time-locked to stimulus onset lasting until 1200 ms post stimulus onset. Segments were averaged separately for each participant, electrode, and condition (e.g., positive correct source).

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1 It is important to verify that artifact rejection methods remove the artifacts but leave the remaining EEG intact (Picton et al., 2000). To this end, we computed ERPs both with and without the artifact correction to determine whether the magnitudes of the ERP waveforms of interest (e.g., frontal and parietal old–new effects) were attenuated by the correction procedure (data not shown).
In an effort to conduct a more focused analysis, ERPs were analyzed from 12 electrode sites (F1, F2, AF3, AF4, F3, F4, C3, C4, CP1, CP2, P3, P4) where condition effects were most evident and where we (Duarte et al., 2004; Dulas et al., 2011) and others (Koeing & Mecklinger, 2008; Swick et al., 2006; Wilding & Rugg, 1996) have reported such effects (i.e., frontal and parietal old–new effects) in similar experimental designs. Furthermore, exploratory analyses performed with a larger set of electrodes yielded similar results as those subsequently reported. Stimulus-locked ERPs were averaged based on participants’ behavioral responses at test. ERPs were averaged separately for negative, positive and neutral items that elicited correct source memory judgments (source correct). ERPs were also averaged for correctly rejected (CR) new items for each separate valence. Given the high levels of item and source memory performance in this study, there were insufficient numbers of incorrect source, “don’t know” source, forgotten (“misses”), and false alarm trials to analyze for both young and older adults. Consequently, ERP analyses here focus on identifying potentials related to source recognition (source correct vs. correct rejections) for positive, negative, and neutral items. Statistical analyses were performed on mean ERP amplitudes for these conditions over the latency windows described below. These data were subjected to the following withingroup and between-group analyses.

First, in order to establish the existence of reliable old–new effects, data from the 12 lateral electrodes listed above were subjected to mixed omnibus ANOVAs including factors of Valence [Negative, Positive, Neutral], Condition [Source Correct, Correct Rejection], Location [Frontotopical (FP1/2), Anterior Frontal (AF3/4), Frontal (F3/4), Central (C3/4), Centroparietal (CP1/2), Parietal (P3/4)], Hemisphere [Left, Right], and Group [Young, Old] were conducted for each valence for 150–250 ms, 300–450 ms, 500–800 ms, 1000–1200 ms time windows. These time windows were chosen based upon visual inspection and previous similar studies which have examined old–new effects for both young and older adults (Duarte et al., 2004; Dulas et al., 2011; Duverne, Motamedinia, & Rugg, 2009; Li, Morcom, & Rugg, 2004; Morcom & Rugg, 2004; Smith, Dolan, & Rugg, 2004; Swick et al., 2006). Preliminary analyses confirmed that there were no reliable old–new effects prior to 100 ms in either group and consequently, no analysis for this time period was conducted. Only effects involving Condition are reported. Second, for the time windows in which old–new effects were reliable for more than one valence, vector length method (McCarthy & Wood, 1985) rescaled difference scores (source correct—correct rejection) were subjected to Valence x Location x Hemisphere x Group ANOVAs in order to determine if any topographical differences were present between valence categories or age groups. This procedure removes the overall amplitude differences between electrodes while preserving information about the shape of the distribution across the scalp for a particular valence. Significant interactions between Valence and Location or Hemisphere are indicative of differences in underlying neural generators. Topographic maps of surface potentials, calculated by spherical spline interpolation (Perrin, Pernier, Bertrand, & Echallier, 1989) were used to display the scalp distributions of the old–new effects.

For all analyses, p-values reflect the Huynh–Feldt correction where appropriate. Huynh–Feldt epsilons are reported where appropriate. Significant interactions at an alpha level of 0.05 were followed up with subsidiary ANOVAs to determine the source of the effects when necessary.

### 3. Results

#### 3.1. Neuropsychological test results

Group characteristics and standard deviations for neuropsychological tests are shown in Table 1. All participants were within two standard deviations of age-adjusted norms, supporting our assertion that older adults were not obviously clinically impaired. Older adults showed significant declines in tests of short and long-term visual memory as measured by Immediate & Delayed Visual recognition, in addition to declines in visuospatial ability and in working memory as measured by Visual Reproduction and Backward Verbal Span tests, respectively [t(26) > 2.01, p < 0.05]. There were no other significant group differences [t(26) < 1.8].

#### 3.2. Behavioral results

Mean proportions of correct, incorrect, and “don’t know” source judgments as well as misses (“new” responses made to studied items), and proportions of correctly rejected and falsely recognized new trial types for negative, positive, and neutral valences are shown in Table 3. Pr measures of discriminability (Snodgrass & Corwin, 1988) were used to estimate item recognition accuracy (p(hits) – p(false alarms)) for each valence separately. Source accuracy was also estimated by Pr, excluding “don’t know”, i.e., p(correct) – p(incorrect). For both Pr estimates, the chance rate is 0%. All estimates were above chance for both age groups [t(5) > 5.0, p < 0.001]. Item and source estimates are shown in Fig. 2.

Previous evidence suggests that older adults have disproportionate impairments for source memory compared to item memory (Mitchell & Johnson, 2009 for review). Given this evidence, we conducted a Valence [Negative, Positive, Neutral] x Memory [Item, Source] x Group [Young, Old] ANOVA on Pr accuracy measures. The ANOVA revealed main effects of Valence [F(2, 56) = 5.5, p = 0.006, ε = 0.81] and Group [F(1, 28) = 25.3, p < 0.001], as well as Memory x Group [F(1, 28) = 4.5, p = 0.04], Valence x Memory x Group [F(2, 56) = 4.4, p = 0.016] interactions. The Memory x Group interaction reflects the fact that older adults showed disproportionate impairments in source relative to item memory. A subsidiary ANOVA examining item memory only revealed main effects of Valence [F(2, 56) = 6.29, p = 0.003, ε = 0.999], Group [F(1, 28) = 17.6, p < 0.001] and a Valence x Group interaction [F(2, 56) = 3.74, p = 0.03]. The main effect of Group reflects the greater item memory estimates, for all valence categories, in the younger than the older adults, as can be seen in Fig 2. Follow-up t-tests showed that, in the older adults, neutral item memory accuracy was greater than both positive [t(13) = 2.32, p = 0.006] and negative [t(13) = 2.44, p = 0.03] estimates, with no reliable differences between positive and negative item memory accuracy [t < 1]. By contrast, there were no significant differences in

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Response proportions and corresponding reactions times to studied and unstudied items at test for young and older adults.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Judgment</td>
<td>Young adults</td>
</tr>
<tr>
<td>Studied items</td>
<td></td>
</tr>
<tr>
<td>Correct</td>
<td>0.53 (0.16) 2020 (235) 0.46 (0.10) 2366 (269)</td>
</tr>
<tr>
<td>Do not know</td>
<td>0.22 (0.14) 2332 (413) 0.12 (0.12) 2707 (557)</td>
</tr>
<tr>
<td>Positive</td>
<td>0.56 (0.14) 1962 (238) 0.50 (0.12) 2238 (296)</td>
</tr>
<tr>
<td>Do not know</td>
<td>0.18 (0.11) 2335 (261) 0.06 (0.08) 2827 (418)</td>
</tr>
<tr>
<td>Neutral Correct</td>
<td>0.63 (0.12) 1830 (212) 0.51 (0.11) 2155 (276)</td>
</tr>
<tr>
<td>Do not know</td>
<td>0.15 (0.11) 2311 (307) 0.07 (0.08) 2731 (213)</td>
</tr>
<tr>
<td>Unstudied items Negative Correct</td>
<td>0.04 (0.04) 1536 (219) 0.80 (0.19) 1905 (333)</td>
</tr>
<tr>
<td>Positive Correct</td>
<td>0.04 (0.05) 1469 (203) 0.81 (0.19) 1779 (306)</td>
</tr>
<tr>
<td>Neutral Correct</td>
<td>0.92 (0.06) 1451 (200) 0.87 (0.12) 1681 (298)</td>
</tr>
</tbody>
</table>

Note: Standard deviations in parentheses.
item memory accuracy between valence categories in the younger group \[t(15)\ís < 1.59, p\ís > 0.13\].

The same subsidiary ANOVA for source memory estimates revealed main effects of Valence \[F(2, 56) = 5.46, p = 0.007, \varepsilon = 1\] and Group \[F(1, 28) = 18.5, p < 0.001\]. The main effect of Group reflects the greater source memory estimates in the young than the old while the main effect of Valence reflects the fact that both neutral and positive source memory estimates were greater than negative estimates \[t\ís > 2.84, p\ís < 0.01\], with no significant differences between positive and neutral source memory estimates \[t\ís < 1\]. These results suggest that the emotional nature of the stimuli, regardless of valence, impaired item memory accuracy in the old but had no significant impact on these same estimates in the young. By contrast, source accuracy was lowest for negative items in both groups.

Mean reaction time data are shown for each response type in Table 3. For consistency with ERP analyses, an ANOVA with factors of Response [Source Correct, Correct Rejection], Valence [Negative, Positive, Neutral], and Group [Young, Old] was performed. The ANOVA revealed main effects of Valence \[F(2, 56) = 44.2, p < 0.001, \varepsilon = 0.968\], Response \[F(1, 28) = 145.9, p < 0.001\] and Group \[F(1, 28) = 14.4, p = 0.001\]. As can be seen in the table, the main effect of Response reflects the fact that younger adults were faster to respond than were older adults, while the main effect of Response reflects the fact that for both groups, correct rejections were faster than correct source responses. Across response category and group, responses were fastest for neutral items and slowest for negative items \[t\ís > 2.18, p\ís < 0.05\].

3.3. ERP results

ERPs associated with correct source judgments for the negative, positive, and neutral valences, as well as for correctly rejected new items for each valence are shown for selected electrode sites in Fig. 3 for the younger adults, and Fig. 4 for the older adults. For both groups, widespread old–new effects similar to those reported in previous studies (see Section 1) were observed, with correct source ERPs for each task eliciting more positive-going activity than correct rejection ERPs beginning at roughly 100 ms post-stimulus. The distributions of the old–new effects for each valence category can be seen topographically for each time window in Fig. 5 for young and in Fig. 6 in the old.

3.3.1. 150–250 ms

A Valence \× Condition \× Location \× Hemisphere \× Group ANOVA revealed a main effect of Condition \[F(1, 28) = 9.85, p = 0.004, \varepsilon = 1\] that was modified by interactions with Location \[F(1, 28) = 2.88, p = 0.04, \varepsilon = 0.53\], Hemisphere \[F(1, 28) = 14.7, p = 0.001, \varepsilon = 1\], and a 3-way interaction with Hemisphere and Location factors \[F(5, 140) = 2.81, p = 0.03, \varepsilon = 1\]. Importantly, a Valence \× Condition \× Location \× Hemisphere \× Group interaction was also observed \[F(10, 280) = 1.16, p = 0.05\]. As can be seen in Figs. 5 and 6, old–new effects were left-lateralized and localized to central and posterior scalp sites in both age groups. Subsidiary ANOVAs for the young adults showed that negative old–new effects were observed (main effect Condition: \[F(1, 15) = 8.72, p = 0.01\]), but neither positive nor neutral old–new effects were reliable in this time window (effects involving Condition: \[F(5, 75) = 2.6, p > 0.12\]). By contrast, subsidiary ANOVAs for the older adults showed that positive (Condition \times Location: \[F(1, 13) = 3.49, p = 0.01\]) but not negative or neutral old–new effects were reliable (effects of Condition: \[F(5, 75) < 1.9, p > 0.1\]). As can be seen in Fig. 6, positive old–new effects were localized to central and posterior scalp sites in the old.

3.3.1.1. Summary

Both age groups showed left-lateralized posterior maximal old–new effects in this window, with young adults showing negative old–new effects only and older adults showing positive old–new effects. Thus, negative old–new effects were the first to emerge in the young while positive effects were the first to emerge in the old.

3.3.2. 300–450 ms

For the 300–450 ms time window as in the previous window, the omnibus ANOVA revealed a main effect of Condition \[F(1, 28) = 30.9, p = 0.0001, \varepsilon = 1\] that was modified by interactions with Hemisphere \[F(1, 28) = 27.6, p < 0.0001, \varepsilon = 1\] and a 3-way interaction including Hemisphere and Location \[F(5, 140) = 4.72, p = 0.002, \varepsilon = 0.76\]. No effects involving Valence or Group were observed in this window \[F(5, 75) < 2.6, p > 0.1\] suggesting that old–new effects did not reliably differ in magnitude either between valence categories or groups. As can be seen in Figs. 5 and 6, old–new effects were evident over left frontocentral scalp sites for all valence categories in both age groups.

The ANOVA comparing the rescaled difference scores (see Section 2.6: EEG Analysis) between valence categories and age groups revealed a Valence \× Hemisphere interaction \[F(2, 56) = 8.04, p = 0.001, \varepsilon = 1\] but no effects involving Group \[F(5, 75) > 0.09\]. Subsidiary ANOVAs showed that while negative and neutral old–new effects had similar topographies (all interactions with Valence \[F(5, 75) < 1\]), positive old–new effects were especially left-lateralized relative to both negative: Hemisphere \× Valence \[F(1, 28) = 8.5, p = 0.007, \varepsilon = 1\] and neutral: Hemisphere \× Valence \[F(1, 28) = 11.9, p = 0.002, \varepsilon = 1\].

3.3.2.1. Summary

Both young and older adults showed left frontocentral old–new effects for negative, positive and neutral valences that did not differ in magnitude either within or between groups. Topographical analyses (i.e., rescaled data) confirmed that for both groups, positive old–new effects were especially left-lateralized compared to negative and neutral effects.
3.3.3. 500–800 ms

The omnibus ANOVA revealed a main effect of Condition \([F(1, 28) = 35.3, p < 0.0001, \varepsilon = 1]\) that was modified by interactions with Hemisphere \([F(1, 28) = 10.2, p = 0.003, \varepsilon = 1]\), Location \([F(5, 140) = 5.24, p = 0.004, \varepsilon = 0.51]\), and Valence \([F(2, 56) = 7.6, p = 0.002, \varepsilon = 0.94]\). A Condition \(\times\) Location \(\times\) Valence \(\times\) Group interaction was also observed \([F(10, 280) = 2.1, p < 0.05, \varepsilon = 0.9]\).

As can be seen in Figs. 5 and 6, old–new effects were left-lateralized and localized to central and posterior scalp sites in both age groups. Subsidiary ANOVAs confirmed that negative old–new effects were more robust than both positive: Condition \(\times\) Valence \([F(1, 28) = 23.4, p < 0.001, \varepsilon = 1]\) and neutral: Condition \(\times\) Valence \([F(1, 28) = 5.96, p = 0.02, \varepsilon = 1]\) old–new effects, the latter of which did not reliably differ: Condition \(\times\) Valence \([F(1, 28) = 1.4, p = 0.25, \varepsilon = 1]\). Furthermore, the Condition \(\times\) Location \(\times\) Valence \(\times\) Group interaction reflects the fact that negative: Condition \(\times\) Group \([Fs > 4.0, ps < 0.05]\) but not neutral or positive: Condition \(\times\) Group \([Fs < 2.9, ps > 0.1]\) old–new effects were reduced in magnitude for central, centroparietal, and parietal locations in the old relative to the young.

The ANOVA comparing the rescaled difference scores (see Section 2.6: EEG Analysis) between valence categories and age groups revealed a Location \(\times\) Group interaction \([F(5, 140) = 2.75, p < 0.05]\). As can be seen in Figs. 5 and 6, old–new effects were localized to left posterior scalp sites in the young with additional anterior distributions in the old.

3.3.3.1. Summary. Both young and older adults showed left centro-posterior maximal old–new effects that were largest for negative items. Negative old–new effects were reduced in magnitude in older adults relative to young adults. Topographical comparisons suggested that old–new effects were more frontally distributed in the old than the young across valence type.

3.3.4. 800–1000 ms

The omnibus ANOVA revealed a main effect of Condition \([F(1, 28) = 4.4, p = 0.04, \varepsilon = 1]\) that was modified by an interaction with Hemisphere \([F(1, 28) = 11.6, p = 0.002, \varepsilon = 1]\). Subsidiary ANOVAs confirmed that old–new effects were reliable at left \([F(10, 280) = 8.4, p = 0.007]\) but not right \([F < 1]\) scalp sites in this window. No effects involving Valence or Group were observed \([Fs < 1.7, ps > 0.2]\).

The ANOVA comparing the rescaled difference scores (see Section 2.6: EEG Analysis) between valence categories and age groups revealed a main effect of Hemisphere \([F(1, 28) = 10.2, p = 0.004, \varepsilon = 1]\) but no effects involving Valence or Group \([Fs < 1]\).

3.3.4.1. Summary. Both young and older adults showed exclusively left-lateralized old–new effects that did not differ in magnitude or topography either within or between groups.
3.3.5. 1000–1200 ms
The omnibus ANOVA revealed a Condition x Valence interaction \([F(2, 56) = 3.3, p = 0.04, \varepsilon = 1]\). Subsidiary ANOVAs confirmed that negative \([F(1, 28) = 8.0, p = 0.008, \varepsilon = 1]\) but not positive or neutral \([F's < 1]\) old–new effects were reliable in this window. As can be seen in Figs. 5 and 6, a negativity was observed for old items (i.e., correct rejection > source correct) across the scalp in both age groups. No effects involving Group were observed in this time window \([F's < 1.1, p's < 0.3]\).

The ANOVA comparing the rescaled negative old–new difference scores (see Section 2.6: EEG Analysis) between age groups revealed no effects involving Group \([F's < 1.8, p's > 0.18]\).

3.3.5.1. Summary. Both young and older adults showed small but reliable new > old effects for negative items only.

4. Discussion
In the present experiment, we examined the effects of emotional salience on source memory accuracy in young and older adults and whether emotional salience might affect the commonly observed age-related differences in onset latency and magnitude of source memory retrieval ERPs. First, contrary to our prediction that emotion-induced source memory impairments would be minimal or absent for the conceptual encoding tasks used here, we found that source memory accuracy was reduced for negative items in both the young and old. Second, ERP results showed that parietal old–new effects were larger for negative than positive or neutral items for both young and old and furthermore, negative old–new effects were attenuated in the old compared to the young. Finally, retrieval of emotional events occurred earlier than retrieval of neutral events in both age groups, and in the same early latency (~100 ms) for both groups. Specifically, old–new effects emerged first for negative items in the young and positive items in the old. These findings provide new insights into the effects of emotional salience on age-related changes in source memory retrieval and associated ERPs. These results and their implications are discussed in more detail below.

4.1. Behavioral results
Given that previous studies have often found enhanced item recognition for emotional compared to neutral items in both young and older adults (Denburg et al., 2003; Kensinger, 2009; Otani et al., 2007; Waring & Kensinger, 2009) it may seem surprising that we did not find same benefits here. In fact, emotional salience negatively impacted recognition for both negative and positive items in the old. There are a few potential explanations for these discrepant results. First, the lack of effect in
the young may be partially explained by the short delay, a few minutes, between study and test. Previous evidence suggests that the memory enhancing effects of emotion are most pronounced at longer delays (> 24 h or more) (Sharot & Phelps, 2004; Waring & Kensinger, 2009) likely due to the impact of sympathetic activation on consolidation mechanisms that occur during the delay (McGaugh, 2000). A similar lack of emotion-induced benefit to item recognition has been observed for short delays in some previous studies (Johansson et al., 2004; Maratos, Allan, & Rugg, 2000; Van Strien et al., 2009; Windmann & Kutas, 2001). A second non-mutually exclusive possibility is that, because item memory estimates were high in the current study, close to ceiling in the young, there was little room for an emotion-induced benefit.
Regarding the emotion-induced impairment in item memory estimates for the older adults, results show that elevated false alarm rates for negative and positive new items, not greater miss rates for studied items, account for the reduction in the Pr estimates of accuracy. A similar pattern has been shown in some previous studies for young adults (Danion, Kauffman-Muller, Grange, Zimmermann, & Greth, 1995; Maratos et al., 2000) and has been explained in terms of greater semantic cohesiveness/overlap for emotional compared to neutral items, typically words (LaBar & Phelps, 1998). Given that older adults are believed to rely on gist to a greater extent than the young when making recognition memory decisions (Brainerd & Reyna, 2001), the semantic cohesion argument could at least partially account for the results in the old. Another explanation may relate to the 4-way memory decision used in the current study (Old source 1/Old source 2/New do not know source/New). The different patterns of results across item and source memory estimates for both groups make it clear that these decisions were not completely correlated. However, it could be the case that for at least some trials, item-level decisions were confounded with source-level decisions and source errors, which were greater for emotional than neutral images, contaminated item memory estimates. Resolution of these issues will require further study. Collectively, these results are consistent with the idea that a number of factors, including study design, memory delay, stimulus type, etc. may influence the degree to which emotion influences memory accuracy in the young and old (reviewed in Murphy & Isaacowitz (2008)).

Our primary interest regarding the behavioral data was to determine whether the use of a conceptual encoding task that facilitated item-source integration would ameliorate the emotion-induced memory impairments often observed for peripheral, low priority event details, like spatial location and scene backgrounds, when presented with both negative (Denburg et al., 2003; Kensinger et al., 2005; Maratos et al., 2000) and positive items (Mather et al., 2006; Waring & Kensinger, 2009) in the young and old. However, we found source accuracy for the conceptual encoding task was reduced for negative items to a similar degree for both age groups. Thus, it seems that when to-be-remembered items are negative or particularly arousing, as the negative items were here, memory for a variety of episodic details suffers, even those arguably more easily bound during encoding. It is worth noting that no source memory impairments were observed for positive items in either group, suggesting that conceptual episodic information can be well-integrated with emotional items, at least when they are only moderately arousing. This pattern is broadly consistent with previous evidence showing that tradeoff effects for background scenes are larger for high arousal negative items but minimal for low arousal negative items in the young and old. Our data are consistent with the idea that while emotion may enhance binding of neutral episodic features that are most intrinsically linked to the items, like font color (Doerksen & Shimamura, 2001; Kensinger & Corkin, 2003) and presentation modality (Kensinger et al., 2007; Kensinger et al., 2007; Kensinger & Schacter, 2006b, 2006) it reduces binding for more extraneous perceptual and conceptual features. Future studies directly comparing memory accuracy for various kinds of neutral source details (conceptual, perceptual) while simultaneously varying the arousal of emotional items would be important for determining the extent to which emotion-induced episodic memory impairments or enhancements are observed.

It is important to point out that although our objective source memory measure indicated that episodic memory was impaired for negative events, it does not suggest that episodic memory was generally impaired for negative items. For example, it is quite possible that negative events were recollected with as much or even more contextual information as were positive and neutral events but this information was not necessarily relevant to the source memory judgment (i.e., “non-critical recollection”). Indeed, this may be one potential explanation for the elevated numbers of “don’t know source” responses for negative compared to neutral and positive images in both groups. Attention toward arousing qualities of the negative images during encoding may have attenuated binding of the neutral conceptual encoding context but enhanced binding for perceptual features or even internally generated associations, like thoughts and feelings about the stimuli. This hypothesis is supported by findings in the young and old showing greater subjective estimates of recollection (Comblain et al., 2004) as well as greater memory for intrinsic perceptual details (Kensinger et al., 2007; Kensinger et al., 2007) for negative than for positive or neutral items.

Finally, both young and older adults were faster to respond to neutral than to emotional items. Specifically, RTs were fastest for neutral items and slowest for negative items, with RTs for positive items falling in between. There are a few potential explanations for this. One possibility, and the one that we favor, is that because these both negative and positive images are more arousing than neutral ones, they capture attention in a way that draws it away from the relevant task and response times are slowed as a result. The fact that the pattern of RTs was the same as the pattern of arousal (i.e., negative > positive > neutral) is consistent with this idea. It should be noted that in at least one previous recognition memory study, both valence and arousal affected RTs, with negative images being associated with slower RTs than positive images, even when arousal was matched (Van Strien et al., 2009). Thus, while arousal may cause a narrowing of attention resulting in slower recognition memory decisions, negative items may further impact response times perhaps due to the adverse impact of negative emotion on semantic processing (Sakaki, Gorlick, & Mather, 2011) that was likely engaged to meet the demands of making semantic source memory decisions (Johnson et al., 1993).

4.2. ERP results

Before discussing the ERP results, it should be noted that the difference between correct source trials and correct rejections was utilized to assess the neural correlates of source memory accuracy, as has been used in similar previous studies (Dulas et al., 2011; Li et al., 2004; Mark & Rugg, 1998; Swick et al., 2006; Wegesin et al., 2002). While activity associated with recollection is undoubtedly represented in this comparison, some degree of familiarity may also be represented, as correct source trials are also more familiar than correctly rejected new items. Thus, one caveat of the old–new effect comparisons is that they may reflect differences in recollection and/or familiarity. We will return to this issue when we discuss each of the ERP effects.

4.2.1. Old–new effects emerge earliest for negative items in the young and for positive items in the old

It has been suggested, based on evidence of spared emotional enhancement in item recognition under divided attention, that emotional information is retrieved with “less effort” than is neutral information (Clark-Foos & Marsh, 2008). Behavioral evidence showing that multiple item repetitions during study, a manipulation likely to enhance encoding and produce robust memory traces, increases location source memory for emotional compared to neutral images in older adults is consistent with this idea (Nashiro & Mather, 2011a, 2011b). Previous ERP evidence of larger early onsetting (~200 ms post retrieval probe) old–new effects for negative than neutral (Schafer et al., 2010) or positive (Van Strien et al., 2009) images in the young suggests that early retrieval mechanisms may contribute to recognition of emotional, particularly
negative, events. Given the differential biases toward negative and positive information often observed for the young and old, respectively, in both attention and memory studies (reviewed in Mather & Carstensen (2005)), one prediction we had for the current study was that this early onsetting old–new effect might be most evident for positive items in the old. Indeed, one of the most interesting findings in the current study was the differential impact of valence on old–new effect onset latencies for the young and old. Specifically, in the young, positive-going old–new effects emerged within 150–250 ms post-retrieval probe for negative but not positive or neutral items while in the old, this early effect was reliable for positive items only. This pattern is broadly consistent with previous evidence showing reduced negativity biases during categorization (Kisley, Wood, & Burrows, 2007; Wood & Kisley, 2006) and encoding (Langeslag & van Strien, 2009) of emotional images in aging as measured by the magnitude of the late positive potential (LPP), an ERP associated with engagement of attentional resources for processing affective material (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Sabatinelli, Lang, Keil, & Bradley, 2007; Schupp et al., 2000).

Furthermore, Langeslag and van Strien also identified a positivity-induced enhancement of the LPP in the older adults only. 

4.2.2. Effects of aging on magnitude and topographies of neutral and positivity effects in the young and old, respectively.

These old–new effects are somewhat reminiscent, although more widely distributed here, of frontal-maximal P2 effects that distinguish all correctly recognized items, regardless of “remember” or “know” judgment (Duarte et al., 2006, 2004) or amount of episodic information retrieved (Tsivilis, Otten, & Rugg, 2001) from correctly rejected new items at approximately 150–200 ms post-retrieval probe. It has been suggested that these early old–new effects may reflect familiarity (Duarte et al., 2006, 2004) or perhaps perceptual priming (Curran & Dien, 2003; Tsivilis, Otten, & Rugg, 2003). Without a direct measure of priming or ERPs for missed (forgotten) items, which would be expected to elicit perceptual priming but not familiarity, we cannot distinguish between these possibilities here. Collectively, these onset latency results suggest that retrieval efficiency is enhanced for negative items in the young and for positive items in the old.

Further work incorporating the use of direct measures of familiarity and priming in conjunction with source judgments will be necessary to determine the extent to which these automatic processes contribute to source recognition for negative and positive events in the young and old, respectively. Nonetheless, these data provide neural support for the theory that emotional information is retrieved more automatically than is neutral information across the lifespan (Zajonc, 1980) and furthermore, that the differential valence biases often described in behavioral studies of aging are evident early during episodic retrieval.

One final point to discuss with regard to the observed interaction between age and valence for the early old–new effects is the fact that there was no evidence of similar biases in the behavioral data. However, given evidence suggesting that the positivity effect in the old is at best, inconsistent in both attention and memory studies (Murphy & Isaacowitz, 2008), it is not terribly surprising that we did not observe this effect here for either item or source accuracy measures. What this inconsistent pattern of results suggests is that episodic memory estimates, which likely reflect the contribution of several processes including priming, familiarity and recollection, may not always be sensitive to detecting the differential valence biases between the young and the old. Future studies that assess separate estimates of these processes may be more likely to detect negativity and positivity effects in the young and old, respectively.

4.2.2. Effects of aging on magnitude and topographies of neutral and emotional old–new effects

Although emotion enhanced the contribution of earlier onsetting retrieval mechanisms in both groups as described above, there was no similar modulation for the FN400 effect, consistent with previous studies in the young (Johansson et al., 2004; Langeslag & Van Strien, 2008; Maratos et al., 2000; Windmann & Kutas, 2001). Given the linkage between this old–new effect and familiarity (see Friedman & Johnson, 2000; Mecklinger, 2006; Rugg & Curran, 2007 for reviews) or perhaps conceptual priming (Voss, Lucas, & Paller, 2009), these data suggest that emotion did not impact the contribution of these mechanisms to source memory judgments. By contrast, both groups demonstrated larger old–new effects for negative items than both positive and neutral items between 500–800 ms. The timing and topography of this effect suggests that it reflects the parietal old–new effect, a purported index of recollection (Curran & Cleary, 2003; Duzel, Yonelinas, Mangun, Heinze, & Tulving, 1997; Friedman, 2000; Paller, Bozic, Ranganath, Grabowecky, & Yamada, 1999; Rugg & Curran, 2007). Given that the magnitude of this effect is believed to be proportional to the amount of information recollected (Vilberg, Moosavi, & Rugg, 2006) this finding suggests that more details were recollected for items associated with negative than either positive or neutral episodes. These results are consistent with previous findings in the young showing larger parietal old–new effects for negative than neutral events both from studies of item memory retrieval (Inaba et al., 2005; Johansson et al., 2004; Langeslag & Van Strien, 2008) as well as those incorporating direct measures of recollection including subjective remember/ know (Schafer et al., 2010), confidence (Weymar et al., 2009), and source memory judgments (Koenig & Mecklinger, 2008). Collectively, these ERP results are consistent with extensive behavioral data showing that negative information tends to be recognized on the basis of recollection to a greater extent than neutral or positive information for both young (Comblain et al., 2004; D’Argembeau & Van der Linden, 2005; Doerksen & Shimamura, 2001; Dolcos, LaBar, & Cabeza 2004; Johansson et al., 2004; Kensinger & Corkin, 2003; Ochsner, Bonnard, Chauplannaz, & Kuntzer, 2000) and older adults (Comblain et al., 2004).4

The enhanced parietal old–new effects observed for negative items may seem at odds with the fact that source memory accuracy was reduced for these same items in both age groups. This discrepancy suggests that negative items were likely associated with more detailed episodic information than positive or neutral items but this information was not relevant for the conceptual source judgment (i.e., non-criterial), as discussed earlier. That is, although correct source judgments reflect retrieval of the sought after source information for each valence type, we believe that additional details were likely retrieved for negative items. Although we cannot determine what kinds of additional episodic details might have accompanied correct source responses in the current study, previous findings have shown that both young and older adults are more likely to remember specific visual details about negative than positive or neutral events (Kensinger et al., 2007; Kensinger et al., 2007).

Indeed, fMRI evidence from the young and old of greater activity.
in the right fusiform gyrus, a visual association cortical region implicated in processing specific visual details of images (Buckner et al., 1998; Koutstaal et al., 2001; Reber, Gitelman, Parrish, & Mesulam, 2005), during encoding of negative compared to positive or neutral events is consistent with this hypothesis (Kensinger & Schacter, 2008). While enhanced attention for these perceptual details may have hindered the ability of young and older adults to bind the task relevant conceptual source features in the current study, we predict that memory for negative items would be enhanced if recollection were subjectively measured or if the if the sought-after source details were perceptual features (see Mitchell & Johnson, 2009 for review). It should be noted that although successful recollection is typically associated with faster response times than unsuccessful recollection (e.g., Duarte et al., 2006; Dulas & Duarte, 2011; Duverne, Habihi, & Rugg, 2008), negative correct source decisions were the slowest in the current experiment for both age groups. We believe the slow response times for negative items coupled with the larger parietal old–new effects for these same items is actually consistent with our hypothesis that negative items may have been associated with recollection of additional non-criterial details compared to positive or neutral items. That is, because the sought after source details did not come to mind as readily as non-criterial ones for negative items, additional memory searches/monitoring may have been engaged in order to make source decisions for these items accounting for the longer response times.

Older adults demonstrated reduced parietal old–new effects for each negative items relative to the young. This suggests that although negative emotion enhanced the recollection for both groups, recollection deficits were still evident in the old. One caveat with concluding that older adults cannot use recollection as effectively as the young during episodic retrieval is the fact that lower levels of source accuracy in the old may indicate that a greater proportion of guesses contaminate their correct source responses, diluting the neural indices of episodic memory (Li et al., 2004; Rugg & Morcom, 2005). We attempted to reduce this potential contamination with the use of the “don’t know source” judgment, however, older adults did not use this response option as often as the young and we cannot rule out the possibility that source accuracy estimates and old–new ERPs are partially contaminated by guesses. It is worth noting that no age-related attenuations were observed for the FN400 old–new effect, which would be predicted if performance dilution confounded all age-group comparisons for neural correlates of memory accuracy. Thus, we tentatively suggest that while negative events were more likely to be recognized on the basis of recollection than positive or neutral events in both groups, older adults were less able or efficient in using recollection overall in the context of this study.

It is interesting to note that topographical analyses showed that old–new effects between 500–800 ms were localized to posterior scalp sites in the young but additional anterior activity was shown in the old for each valence. These results are somewhat consistent with findings from a number of cognitive tasks including episodic retrieval (Daselaar, Veltman, Rombouts, Raaijmakers, &Jonker, 2003; Davis, Dennis, Daselaar, Fleck, &Cabeza, 2008; Madden et al., 1999) in which posterior activity reductions are coupled with increases in anterior neural activity, which are hypothesized to reflect age-related functional compensation. A somewhat speculative hypothesis is that frontally-mediated cognitive control mechanisms came online in response to under-recruitment of more posterior-mediated recollective processes. It is also possible that the topographical differences suggest that young and older adults relied on somewhat distinct kinds of information to support their episodic memory decisions. Although the poor spatial resolution of ERPs does not allow us to distinguish between these possibilities here, it is worth noting that group differences in spatial distribution were observed across valence category.

Late-onsetting (~800–1400 ms) right frontal maximal old–new effects are sometimes observed in source retrieval studies (Senkfor & Van Petten, 1998; Trott et al., 1997; Wegesin et al., 2002; Wilding & Rugg, 1996) and proposed to reflect the engagement of frontally-dependent strategic processes, including monitoring and evaluation of the products of retrieval in service of a memory decision (Cruse & Wilding, 2009). We had predicted that if source memory accuracy was enhanced by the emotional salience of the items, the demands on strategic retrieval and the magnitude of late onset frontal old–new effects might have been reduced. Instead, we found no evidence for this effect in either age group for any valence. It has been suggested that the strategic processes underlying this old–new effect may be particularly necessary when the sought after information, i.e., source-specifying details, are difficult to recover (Senkfor & Van Petten, 1998). Given the relatively high levels of source accuracy observed across all valence categories relative to the levels observed in many previous source retrieval ERP studies, it is not entirely surprising that we did not observe this effect here (see Dulas et al., 2011; Swick et al., 2006 for similar arguments). Interestingly, a reliable negativity was observed for old items between 1000 and 1200 ms for negative items only in both age groups. A late-onsetting negativity elicited by old items is often observed in source retrieval studies in young and older adults (Johansson & Mecklinger, 2003 for review; Li et al., 2004; Trott et al., 1997, 1999; Wegesin et al., 2002; Wilding & Rugg, 1997). This effect has been linked to attempts to recover visual episodic details (Cyczowicz, Friedman, & Snodgrass, 2001) or reconstruction of the prior episode when sought after source details are not readily recovered (Gonsalves & Paller, 2000). Both of these accounts fit with our proposal that negative items may have induced item-source trade off effects such that recollection of non-criterial most likely visual information was high at the expense of reduced memory for conceptual source details, which in turn may have led to attempts to reconstruct the encoded event.

4.3. Potential limitations

It is important to note that we could not match positive and negative images for absolute arousal level. It is therefore possible that some of the behavioral and ERP effects of valence are actually attributable to the different levels of arousal, which were greater for negative items in both groups. However, we do not feel that the effects observed here are solely the result of differences in arousal. First, some previous evidence of tradeoff effects in memory for background scenes has been observed for high arousal images, both negative and positive but also for low arousal negative but not low arousal positive images in the young and old (Waring & Kensinger, 2009). Thus, although arousal may contribute to the source memory impairment for negative stimuli in the current study we believe the negative content is also important. Second, some previous evidence from young adults has shown that magnitude of the early P2-like old–new effect for negative images (positive images were not assessed) is sensitive to arousal (Schaefer et al., 2010). However, given that both age groups judged negative items to be more arousing than positive items and positive items to be more arousing than neutral items (negative > positive > neutral), the absence of a P2 old–new effect for negative items in the older adults is not consistent with an arousal account. Third, these same authors found that the parietal old–new effect is also sensitive to arousal but follows a U-shaped function, with medium level arousal items demonstrating the largest magnitude effect (high < medium < low/neutral) in young
adults. Accordingly, one would have predicted the parietal old–new effects to be largest for positive items for both age groups in the current study when in fact they were the smallest. Finally, in order to directly assess the influence of arousal in the current study, we divided negative and positive items into high and low arousal categories for each age group separately and reanalyzed source accuracy and the old–new ERPs (see Supplemental results). The only reliable effect of arousal was found for the early P2-like old–new ERP that appeared to driven largely by low arousal negative items in the young, as seen in Supplemental Fig. 1. This pattern in the young is somewhat consistent with behavioral findings suggesting that the negativity effect in young adults is most pronounced for low arousal items (Kensinger, 2008). It was suggested that elaborate encoding mechanisms may be disproportionately engaged for low arousing compared to highly arousing stimuli. If low arousal negative items were more elaborately encoded by young adults in the present study, it seems reasonable that they would be retrieved automatically via early retrieval processes like those linked to the P2. Although these results should be treated with caution given the reduced number of participants available for this analysis, we suggest that the influence of arousal on the behavioral and ERP effects reported in the manuscript is minimal. To the extent that arousal can be matched both across valence categories and age groups, future studies would benefit from assessing the separate contributions of arousal and valence on the ERP effects shown here.

Although we focused our investigation on the effect of emotion on source memory retrieval, it should be noted that we could not assess activity associated with source memory encoding, i.e., subsequent memory effects (Paller, Kutas, & Mayes, 1987), because of an insufficient number of item misses. However, we think it is likely that emotion-induced modulations would also be observed for subsequent memory ERP effects. The socioemotional selectivity theory suggests that older adults focus on emotional information in the environment, particularly positive information, to a greater extent than the young (reviewed in Lockenhoff & Carstensen, 2004). One prediction we can make is that encoding-related ERPs may show a similar pattern of bias, perhaps with earlier onsetting subsequent memory effects for positive images in the old and for negative images in the young. Such a pattern of results would complement that observed here for the early onsetting retrieval effects and suggest that the differential impact of valence on memory in the young and the old is likely a consequence of both attentional mechanisms that affect episodic encoding and automatic retrieval mechanisms like perceptual priming and/or familiarity.

4.4. Conclusions

These data are consistent with the idea that multiple memory processes, both relatively automatic processes like priming and effortful processes like recollection and monitoring contribute to episodic retrieval for emotional events to a greater extent than neutral events across the lifespan. We have shown that very early retrieval mechanisms like familiarity or perceptual priming may underlie the negativity and positivity effects sometimes observed in the young and old, respectively, for various behavioral measures of attention and memory. Importantly, these differential emotional biases were not also evident in the behavioral estimates of item or source memory accuracy. Thus, we believe that it will be important for future studies investigating age-related changes in emotional memory processing to include separable estimates of these aforementioned implicit and explicit memory processes in order to detect these biases.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.neuropsychologia.2012.09.024.

References


