Published in final edited form as:

Psychol Aging. 2013 March ; 28(1): 179–190. doi:10.1037/a0030928.

Brain Responses to Emotional Images Related to Cognitive Ability in Older Adults

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Abstract

Older adults have been shown to exhibit a positivity effect in processing of emotional stimuli, seemingly focusing more on positive than negative information. Whether this reflects purposeful changes or an unintended side-effect of declining cognitive abilities is unclear. For the present study older adults displaying a wide range of cognitive abilities completed measures of attention, visual and verbal memory, executive functioning, and processing speed, as well as a socioemotional measure of time perspective. Regression analyses examined the ability of these variables to predict neural responsivity to select emotional stimuli as measured with the late positive potential (LPP), an event-related brain potential (ERP). Stronger cognitive functioning was associated with higher LPP amplitude in response to negative images (i.e., greater processing). This does not support a voluntary avoidance of negative information processing in older adults for this particular measure of attentional allocation. A model is proposed to reconcile this finding with the extant literature that has demonstrated positivity effects in measures of later, controlled attentional allocation.

Keywords

aging; emotion; cognition; negativity bias; positivity effect

Aging has been associated with changes in the processing of emotional information. Whereas younger adults are more attentive to, and affected by, negative compared to positive stimuli (Baumeister, Bratslavsky, Finkenauer, & Vohs, 2001; Cacioppo & Berntson, 1994), older adults appear to exhibit a positivity effect, focusing more on positive rather than negative stimuli (Carstensen & Mikels, 2005; Mather & Carstensen, 2005). Although not universally confirming, findings from diverse methodological approaches converge to support the idea that older adults exhibit a prioritization of emotionally positive compared to negative information (reviewed by Murphy & Isaacowitz, 2008). The present study was designed to investigate whether such effects may arise from voluntary, controlled processes or rather represent an involuntary phenomenon associated with reduced cognitive function.

There are abundant demonstrations of positivity effects in older adults. In the domain of memory, the proportion of negative to positive information recalled decreases across the adult lifespan (Charles, Mather, & Carstensen, 2003; Leigland, Schulz, & Janowsky, 2004; Mikels, Larkin, Reuter-Lorenz, & Carstensen, 2005; but see Kensinger, Brierly, Medford, Growdon, & Corkin, 2002). In the domain of attention as well, older adults display a processing bias towards positive information (Mather & Carstensen, 2003; but see Mickley Steinmetz, Muscatell, & Kensinger, 2010). For example, eye-tracking studies indicate that

older adults are more likely to focus their attention on the most positive (or least negative) facial expression presented in a pairing (Isaacowitz, Wadlinger, Goren, & Wilson, 2006; Rösler et al., 2005). Further, measurement of regional cerebral blood flow by neuroimaging methodologies has also corroborated positivity effects of brain functioning in older adults (Brassen, Gamer, & Büchel, 2011; Mather et al., 2004; Williams et al., 2006; but see Leclerc & Kensinger, 2011; recently reviewed by St. Jacques, Bessette-Symons, & Cabeza, 2009).

Observation of brain electrical activity, measured through event-related potentials (ERPs), further support positivity effects associated with aging. Wood and Kisley (2006) showed that brain responses of older adults, compared to younger adults, demonstrate a lower prioritization of negative images (see also Kisley et al., 2007; Langeslag & van Strien, 2009). This was shown for a specific ERP, the late positive potential (LPP), which corresponds to underlying neural activity distributed across multiple cortical regions including visual association areas (Keil et al., 2002; Sabatinelli, Lang, Keil, & Bradley, 2007). The amplitude of this component has specifically been linked to the motivational relevance of stimuli (Ferrari, Codispoti, Cardinale, & Bradley, 2008; Schupp et al., 2000).

Whereas positivity effects are supported by a strong literature base, the underlying cause remains unclear. On the one hand, older adults may be *purposefully* attending more to positive than negative information in order to maximize a positive mood state (Mather & Carstensen, 2005). This idea originally grew out of research on Socioemotional Selectivity Theory (SST), which posits that older adults may react differently to emotional stimuli because their primary social goal has shifted to one of emotion regulation (Carstensen, Isaacowitz, & Charles, 1999). Importantly, this perspective leads to the prediction that positivity effects result from voluntary cognitive control processes (Mather & Knight, 2005). In support of this, behavioral measures have shown that older adults revert from apparent positivity effects under full attention conditions to negativity biases under conditions of distraction (Knight et al., 2007). Isaacowitz, Toner, and Neupert (2009) extended these findings to show that older adults with greater executive control were those most likely to display positive gaze preferences and also to resist declines in mood.

A competing perspective for explaining positivity effects in older adults has been argued as follows: age-related changes in brain function lead to cognitive decline which may cause difficulties in processing negative information specifically. This line of reasoning suggests that positivity effects in older adults arise as an *unintended consequence* of aging (Ruffman et al., 2008). Changes in specific neural systems associated with processing negative information (i.e., frontal and temporal cortices) are presumed to lead to such difficulties (Calder et al., 2003; Ruffman et al., 2008). This is supported by findings of axonal degeneration (Allen, Bruss, Brown, & Damasio, 2005) and gray matter loss (Raz, 2000; West, 1996), within specific areas proposed to be essential for emotion processing including the amygdala, the anterior cingulate cortex, the prefrontal cortex, and the orbitofrontal cortex (reviewed by Ochsner & Gross, 2005; Ruffman et al.).

To shed light on the controversy concerning the cause of positivity effects (i.e., voluntary or involuntary), we explored the relationships between brain responsivity to specific emotional images, cognitive abilities, and time perspective in an older adult sample. Specifically, we measured brain responsivity via the scalp-recorded LPP waveform. A broad range of cognitive measures were employed, including those associated with frontal and temporal cortices (i.e., verbal and visual memory, executive functioning, processing speed, and attention; Salthouse, 2000). Time perspective, a socioemotional measure related to goal selection, was also included as were specific demographic variables that might influence emotion processing. Given the existence of two directly competing perspectives, this study was designed to explore the relationships between measures without hypothesizing the

specific directions the relationships may take. As previously observed changes in the LPP reflect decreased negative information processing with relative stability in positive information processing (Kisley et al., 2007), we expected that cognitive abilities and time perspective would display relationships with measures of negative, but not necessarily positive, emotion processing. Hence, we focused our planned analyses on the relationships between brain responsivity to negative images, cognition, and time perspective. We predicted that support for the first perspective, that older adults are voluntarily employing cognitive resources to decrease negative emotional experience, would be associated with decreased processing of negative information being predicted by (a) stronger cognitive abilities, and (b) a limited, rather than expansive, time perspective. Conversely, we hypothesized that support for the second perspective, that older adults avoid negative information involuntarily, would be associated with decreased processing of negative information being predicted by (a) weaker cognitive abilities (b) without a particular relationship to time perspective.

Method

Participants

Participants for the present study were recruited from a community memory clinic with the intention of including individuals with a wide range of cognitive abilities. At the memory clinic, individuals were diagnosed as belonging to one of three categories based on their objective memory performances (measured with Rey Auditory Verbal Learning Task and Benton Visual Retention Task, both described below) and the clinical judgment of a licensed psychologist: (a) those who appear to be aging as expected, without impairment on either memory test (“normal”), (b) those who are showing objective evidence of significant memory impairment and functional declines suggestive of a dementia process (“dementia”), and (c) those who appear to be experiencing mild memory difficulties and/or subjective memory complaints that are not clearly classified into either of the aforementioned groups and who are asked to follow-up at the clinic in one year (“follow-up”). Individuals diagnosed with “dementia” were not recruited for the present study so as to ensure that all participants could fully comprehend instructions and participate in the study. All other individuals were recruited, including those categorized as “normal” and “follow-up.”

In total, 66 individuals participated in this study (41 “normal” and 25 “follow-up”). Participants ranged in age from 53 to 89 years ($M = 68.08$, $SD = 8.27$) and education level ranged from 8 to 23 years ($M = 15.83$, $SD = 2.92$). Approximately two-thirds were female ($n = 43$).

Of the 66 individuals who completed the study, 5 were excluded due to excessive sleepiness during the ERP recording and another 8 following artifact rejection (described below). Independent *t*-tests confirmed that the remaining 53 participants were not significantly different from the overall sample or from the 13 who were excluded on any demographic or cognitive measures. Demographic data for the remaining 53 participants are provided in Table 1. Two other individuals were missing cognitive testing data due to data collection errors; instances where missing data affected sample size are noted in the Results section.

As some measures administered during this study were also included in the Memory Clinic evaluation (i.e., Benton Visual Retention Test, Trail Making A & B, and Rey Auditory Verbal Learning Test), time elapsed between initial Memory Clinic screen and the present study was calculated to consider the likelihood of practice effects influencing interpretation of the cognitive data. Time elapsed ranged from 10 to 25 months ($M = 15.70$, $SD = 2.31$), with the majority of participants (93.9%) completing the study more than 12 months after their initial Memory Clinic screen. Given that test-retest reliability improves significantly

after 12 months (Basso, Bornstein, & Lang, 1999) and that all participants were equally affected by the potential for practice effects this was not considered to be of significant concern here.

Materials

All individuals updated a demographic questionnaire (originally completed at the Memory Clinic), in addition to completing ERP, cognitive, and socioemotional measures. Individuals completed two distinct ERP paradigms and several cognitive and socioemotional measures; only those relevant to this study are described here.

ERP task—Electrophysiological signals were collected on a multi-channel recording system (portable Nu-Amps amplifier, Neuroscan Inc.). Affective images for the categorization task were presented on a computer screen via E-prime software (Psychological Software Tools, Inc., Pittsburgh, PA). Images for this task were chosen from the International Affective Picture System (IAPS; National Institute of Mental Health Center for the Study of Emotion and Attention, 2001). The images used for analysis of neural responses included two positive (7340, chocolate ice cream; 7350, pizza), two negative (9140, decomposing calf; 9571, dead cat), and three neutral (7090, book; 7235, chair; and 7150, umbrella) images. These particular images were selected based on their prior use in ERP studies of both younger (Ito, Larsen, et al., 1998) and older adults (Kisley et al., 2007; Wood & Kisley 2006) to allow for comparisons between studies. These images were equivalent in terms of luminosity and have been affectively rated on valence and arousal with the Self Assessment Manikin instrument (SAM; Lang, Bradley, & Cuthbert, 2005). On this instrument, participants rate the images in terms of (a) valence, described to them as the “happy/unhappy” scale and (b) arousal, described to them as the “excited/calm” scale. Although we planned to include SAMs ratings in the present study to confirm subjective valence and arousal ratings in this population, a systematic data collection error prevented analysis of this data. Therefore the published average ratings for these images are provided here for reference: average bipolar valence (1 = *most negative*, 5 = *neutral*, 9 = *most positive*) for the positive images is 6.89, and average arousal (1 = *least arousing*, 9 = *most arousing*) is 4.33. Mean valence and arousal are 2.08 and 5.51, respectively, for the negative images. For the target neutral images mean valence is 4.96 and mean arousal is 2.68. In past studies from our lab, the subjective rating of these images were similar to the published norms, and did not vary systematically with advancing age (Kisley et al., 2007).

Cognitive measures—All computerized tasks (i.e., Rey Auditory Verbal Learning Test, Reaction Time, Tower of London, and Wisconsin Card Sort) were administered on an IBM-compatible computer with a 17” monitor. The versions utilized in this study were those included in the Colorado Assessment Test (CATs) software (Davis & Keller, 1998).

Trail Making A and B (Reitan, 1979): Trail Making A and B (Trails A & B), two paper-and-pencil tasks, were chosen as measures of basic attention and set shifting (a measure of executive function), respectively (Mitrushina, Boone, & D’Elia, 1999). Trails A is composed of 25 numbers that participants must connect in order, whereas Trails B is made up of letters and numbers that participants must connect in order, alternating between the two (i.e., 1-A-2-B...). For both, standard administration instructions were followed and time to complete the measure was used as the dependent variable (DV). As such, higher scores reflected slower performance (i.e., decreased attention and poorer set shifting).

Rey Auditory Verbal Learning Test (Davis & Keller, 1998): The Rey Auditory Verbal Learning Test (RAVLT) was included as a measure of delayed verbal memory because of its high reliability and sensitivity to early cognitive decline (Lezak, Howieson, & Loring,

2004). The Colorado Assessment Test (CAT), computerized RAVLT required participants to learn and recall 15 concrete nouns. Participants were given six trials, five immediate recall (Rey1, Rey2, etc.) and one delayed recall (Rey Delay). In each of the five immediate recall trials, the words are presented in a different order, at a rate of 1 word per 2 seconds. After a 20-minute delay, the participant is asked to freely recall the words.

The number of words recalled was selected as the dependent measure of delayed verbal memory; as such, higher scores reflected stronger verbal memory. During the initial memory clinic screen participants were given List A; therefore, in this study they were presented with List B to decrease practice effects (Delaney, Prevey, Cramer, & Mattson, 1992; Lemay, Bédard, Rouleau, & Tremblay, 2004).

Benton Visual Retention Test (Sivan, 1992): The Benton Visual Retention Test (BVRT) is a measure of visuospatial memory, consisting of 10 cards depicting one or more figures. It has been shown reliable and sensitive to early cognitive decline (Coman et al., 1999; Lezak et al., 2004). Participants are shown a card for 10 seconds and then asked to draw the stimulus from memory as accurately as possible once it had been removed (Administration A; Sivan, 1992).

Form E was used to decrease practice effects between administration at the Memory Clinic (Form D) and during this study (Lezak et al.; Sivan). The number of cards reproduced accurately (i.e., number correct) was used as the dependent measure of visual memory for this study. A higher score, therefore, captured stronger visual memory.

Reaction Time (Davis & Keller, 1998): Reaction time tasks provide reliable measures of processing speed and inhibition that are sensitive to age- and disease-related processes (Lezak et al., 2004). In the CAT's version, participants complete a motor performance baseline trial (16 trials of press right button when ">" symbol appears, then 16 trials of press left button when "<" symbol appears), followed by a choice reaction time task (32 trials of press left or right button, respectively, when the "<" or ">" symbol appears), and then a conditional reaction time task assessing inhibitory control (32 trials randomly alternating between *standard* trials, reflected by a "+" in addition to directional arrow requiring the participant to press the button corresponding with the symbol, and *inhibition* trials, reflected by a "—" in addition to directional arrow requiring the participant to press the button opposing the symbol).

Time to complete the choice task (Rxn Choice) was used as the dependent measure of processing speed, where higher scores reflected slower processing speed. To account for differing strategies engaged during the conditional reaction time task, inhibition was calculated as the absolute difference between the inhibition and standard trials (Rxn Cond.), with higher scores indicating more difficulty inhibiting a reaction and therefore poorer executive function.

Tower of London (Davis & Keller, 1998): The Tower of London (TOL) was used as a measure of planning ability to tap another aspect of executive functioning. This widely used measure is reliable, valid, and sensitive to frontal lobe deficits (Lezak et al., 2004; Shallice, 1982). The CAT, computerized version requires participants to move beads on the left side of the display (i.e., working screen) to match those on the right side of the display (i.e., goal screen). Problems range in difficulty from two to five moves and the number of beads and pegs varied from three to five.

Total number of excess moves was used as the DV of planning ability and therefore higher scores reflected poorer planning/executive function.

Wisconsin Card Sorting Task (Davis & Keller, 1998): The Wisconsin Card Sorting Task (WCST) is a reliable and valid measure of inhibition, particularly when perseverative errors are used to assess performance (Lezak et al., 2004). The CATs, computerized version of this task requires participants to match cards one at a time to four sample cards. Cards can be matched on the basis of color, shape, or number. Once the participant “matches” the card, the computer then indicates if the move is correct or incorrect. After the participant correctly matches 10 cards in a row, the computer automatically changes the matching criteria. Participants complete 6 sets of categories, or 128 cards, whichever comes first.

The computer tracked the number of categories a participant completed ($WCST_{cat}$) and this was recorded as one of the DVs. A perseverative error, the other DV for this task ($WCST_{pers}$), was counted each time the participant attempted to use a matching criteria the computer had already indicated was incorrect. Whereas higher $WCST_{cat}$ scores reflected ability to shift between cognitive sets and stronger executive function, higher $WCST_{pers}$ scores implied more difficulty inhibiting a previous response and therefore relatively weaker executive function.

Socioemotional Measure—The Future Time Perspective scale (FTP; Carstensen & Lang, 1996) is a socioemotional measure capturing the amount of time an individual feels that he/she has left in the future. Participants rate 10 questions such as “*My future is filled with possibilities*” on a scale from 1 (*very untrue*) to 7 (*very true*). Scores can range from 10 to 70; lower scores reflected a sense that time is limited and higher scores indicated that time is perceived as expansive. Lower scores on this scale have been associated with individuals that place an emphasis on mood regulation (Lang & Carstensen, 2002).

Procedure

An institutional review board approved the study protocol and participants were treated in accordance with APA ethical standards. Informed consent was obtained from each individual and all participants were paid \$10 per hour. Once an individual consented, he/she was screened for vision difficulties. All individuals had corrected vision better than 20/40 on the Snellen visual acuity chart and were thus appropriate for the study. Participants completed the remainder of the study according to one of two protocols, which counterbalanced order of presentation for the electrophysiological and cognitive measures. Once participants completed all components of the study they were debriefed.

The electrophysiological assessment procedure followed standard procedures from our lab (Kisley et al, 2007; Wood and Kisley, 2006). Silver/silver-chloride electrodes were attached to the following locations of the International 10–20 system: Fz, Cz, Pz, right mastoid, and left mastoid. In addition, electrodes were attached above and lateral to the participant’s left eye to monitor eye movements. A ground electrode was attached to the forehead and signals were referenced to the left mastoid during recording. Impedance values were monitored to ensure a maximum impedance value of 10 Ω at all electrodes. Electrophysiological signals were digitized at a rate of 1000 Hz.

We employed the same ERP task previously used in our lab to study emotion processing in younger and older adults, an evaluative categorization of emotional stimuli in an oddball paradigm (Kisley et al., 2007, Wood & Kisley, 2006). Emotionally positive and negative images were presented infrequently in the context of frequent neutral images and participants were asked to indicate whether the image was positive, neutral, or negative using a control pad. Images were shown in blocks of five and an emotional “oddball” (positive or negative) or neutral control image was presented pseudorandomly in the third, fourth, or fifth position. Overall, 90 blocks of 5 images were presented for a total of 450 presentations. Of these, 30 presentations were recorded for neural responsivity to the

positive images (15 presentations each of the 2 positive images), 30 for neural responsivity to negative images (15 presentations each of the 2 negative images), and 30 for neural responsivity to the neutral control images (10 presentations each of the 3 neutral images). The remaining image presentations, which made up the majority of stimuli, provided a neutral context for the task: 24 neutral images were selected from the IAPS database and presented 15 times each, pseudo-randomly. Before beginning the task, participants were shown five positive, five negative, and five neutral images to provide relative emotional anchors as examples for the categorization component of the task.

Participants' behavioral responses were collected as a subjective measure of experienced valence and as an objective measure of "accuracy." In response to each image type participants could select positive, negative, or neutral. As such, there were nine variables associated with the behavioral data. These were labeled with the first three letters of the image type followed by the first three letters of the response: (a) positive, negative, and neutral responses to positive images (PosPos, PosNeg, and PosNeu, respectively); (b) positive, negative, and neutral responses to neutral images (NeuPos, NeuNeg, and NeuNeu, respectively); and (c) positive, negative and neutral responses to negative images (NegPos, NegNeu, and NegNeg, respectively). Accuracy was scored as the number of valence ratings matching the anticipated valence based on published ratings (i.e., PosPos, NeuNeu, and NegNeg). All others were considered "inaccurate." Behavioral response times, time to categorization button press relative to image offset, were also recorded and are shown in Table 1.

For all cognitive tests, directions were given at the beginning of each task and participants were provided an opportunity for and encouraged to ask questions before the testing began. During administration of computerized tasks, the principal investigator reviewed the on-screen directions with the participant and then remained in the room for the first few trials of each task to ensure the participant had a complete understanding of the task requirements and procedures.

Analysis of ERP Data—Analysis of the ERP data followed procedures previously used in our lab to examine the LPP waveform (Kisley et al., 2007; Wood & Kisley, 2006). In particular, after trials with artifact were excluded (i.e., those with voltages exceeding $\pm 100 \mu\text{V}$), valence-specific average waveforms were computed from the remaining trials. Individuals with fewer than 10 trials for each average waveform were excluded ($n = 8$), as were 5 other individuals who displayed excessive sleepiness throughout the experiment. As previous research has suggested that the LPP amplitude is largest at recording site Pz (cf. Ito et al., 1998), data gathered from this electrode were used to compute the valence-specific average waveforms from 100 ms pre-stimulus onset to 900 ms post-stimulus onset. Analyzed waveforms were re-referenced to an average of the right and left mastoids. Finally the average waveforms were smoothed by a low-pass filter at 9 Hz. Three dependent measures were established and used in data analysis: average amplitude of the LPP waveform in response to positive images (PzPos), negative images (PzNeg), and neutral images (PzNeu). These were computed as the mean amplitude between 450 and 650 ms post-stimulus onset.

Primary Statistical Analyses—Correlations were examined between demographic, cognitive, socioemotional, and emotion processing measures to identify which variables should be included in the planned regression analysis. Given this goal, it was considered preferable to overestimate possible relationships than to underestimate them and the p value was set at .05 to evaluate significance, despite the increased risk of a type I statistical error. As change in emotion processing across the lifespan appears to be more closely related to

changes in response to negative information, planned regression analyses were limited to the measure of neural responsivity to negative images (PzNeg).

Hierarchical Regression: First, we used a hierarchical regression analysis to explore how the significantly correlated demographic, cognitive, and socioemotional measures related to PzNeg. The first set of independent variables (IVs) included in the hierarchical regressions consisted of all cognitive and/or socioemotional variables correlated with the DV and the second set included demographic variables. Semipartial (part) correlations, which remove the effects of other IVs only from the IV in question rather than from the IV and DV as is the case for partial correlations, were used to establish the unique variance accounted for by each independent variable *and* to determine the relative importance of the IVs (Keith, 2006). Any IV independently accounting for 5% or more of the variance (part correlation .22) was considered non-trivial and appropriate for interpretation.

Given the limited sample size ($N = 53$), it was not feasible to include all possible IVs in the regression. Following data collection, but prior to data analysis, the following decisions were made to guide selection of IVs. Foremost, only those IVs that were significantly correlated with the DV of interest were included. Additionally, if more than one executive function measure was significantly correlated with the DV, then the one with the strongest correlation was included. This ensured that the variance associated with executive function was captured in the analysis, rather than it being ignored because of its overlap with another executive function variable. Finally, where Trails A and B both displayed significant correlations with the DV, Trails B was excluded. This was done to capture the unique role of basic attention rather than set shifting, an executive function (Mitrushina et al., 1999).

Mediator Analyses: Following the hierarchical analysis, we conducted supplementary mediator analyses. Specifically, we performed a set of regression analyses to determine whether cognitive variables mediate the relationship between time perspective and negative information processing (PzNeg). Whereas it was considered logical for cognitive ability to affect time perspective, the reverse seemed unlikely. As such, where PzNeg correlated significantly with both time perspective and a cognitive measure, a set of regressions was used to determine if the cognitive ability could explain the relationship between time perspective and negative emotion processing. First, a regression was conducted to determine whether time perspective was related to negative emotion processing. Then, a second regression was performed to determine if the cognitive variable related to time perspective. Finally, where the first and second regressions were significant, a third (hierarchical) regression was conducted to determine if the relationship between time perspective and negative emotion processing remained after controlling for the cognitive ability. To maintain consistency, the same participants that were used in the main hierarchical regression analyses were used for the follow-up regressions.

Results

Descriptive Statistics for Independent and Dependent Variables

Means, standard deviations, and range of values for each variable are displayed in Table 1. Correlations between the IVs and DVs are shown in Table 2. As shown in Table 3, age and education were related to the cognitive, but not electrophysiological measures. The relationship between age and time perspective was not significant, but trended in the expected direction (i.e., older individuals tended to view their futures as limited). Time perspective correlated significantly with several cognitive measures, such that viewing the future as expansive was associated with stronger cognitive ability in each domain.

Behavioral Analyses

Table 1 displays descriptive data for response accuracy as percentages. A repeated-measures ANOVA was employed to investigate accuracy across image valence (i.e., comparing NeuNeu, PosPos, and NegNeg). Mauchly's test indicated that the assumption of sphericity had been violated, Mauchly's $W = .589$, $\chi^2(2) = 26.991$, $p < .001$, therefore degrees of freedom were corrected using the Greenhouse-Geisser estimates of sphericity ($\epsilon = .71$). Accuracy varied as a function of valence, $F(1.42, 73.71) = 30.23$, $p < .001$, $\eta^2 = .37$. Participants were significantly more accurate in their response to negative images, than to positive and neutral images (both $p < .001$). Accuracy for positive images was significantly greater than for neutral images as well ($p < .01$). Given the notable variability in behavioral response to neutral images, these were analyzed in greater detail (i.e., comparing NeuNeu, NeuPos, and NeuNeg). Mauchly's test indicated that the assumption of sphericity had been violated, Mauchly's $W = .178$, $\chi^2(2) = 88.123$, $p < .001$, therefore degrees of freedom were corrected using the Greenhouse-Geisser estimates of sphericity ($\epsilon = .55$). The rate of valence selection varied significantly for neutral images, $F(1.10, 57.07) = 27.88$, $p < .001$, $\eta^2 = .35$. Although participants selected a neutral rating (NeuNeu) over a positive rating (NeuPos) for neutral images slightly more often, this difference was not significant ($p = .094$); however, the selection of neutral or positive ratings occurred significantly more often ($p < .001$) than negative ratings (NeuNeg),

Mean response times and standard deviations are shown in Table 1. Overall, these response times suggest that participants were adherent to the task procedures. There were no significant differences in mean response times to the different image valences, $F(2, 51) = 1.92$, $p = .16$, $\eta^2 = .07$.

LPP Analyses

LPP Waveform—To provide an overall picture of the neural responses in general, the grand-averaged LPP waveform for all participants is shown in Figure 1. A one-way repeated measures ANOVA of LPP amplitudes revealed significant main effects for type of emotional image, $F(2, 51) = 5.02$, $p = .01$. LSD post-hoc comparisons confirmed that LPP amplitude was greater in response to negative images than the positive or neutral images. The amplitudes in response to positive and neutral images did not differ significantly ($p = .71$). Figure 2 allows a comparison of the grand-averaged LPP waveform for the “normal” group versus the “follow-up” group. This figure suggests that the “normal” individuals had greater responsivity to negative images than those individuals in the “follow-up” group. An independent samples t -test confirmed that the difference in mean responsivity (PzNeg) was significantly greater for the “normal” group ($M = 7.39$, $SD = 4.00$) than for the “follow-up” group ($M = 5.14$, $SD = 2.92$); $t(48) = 2.15$, $p = .03$.

Correlations with Demographic, Cognitive, & Socioemotional Variables—

Several correlations existed between LPP waveform amplitudes and cognitive measures (Table 2). Overall, the cognitive variables correlated most strongly with average amplitude in response to negative images (PzNeg). A few correlations were also identified between the cognitive variables and average amplitude in response to positive images (PzPos). No significant correlations were found between the cognitive measures and average amplitude in response to neutral images (PzNeu). Across all significant correlations, stronger cognitive abilities were associated with increased neural responsivity to emotional images, regardless of valence. Likewise, the socioemotional measure (FTP) was also correlated with PzNeg and PzPos, but not PzNeu. In both cases, the correlation between FTP and average amplitude was positive, such that viewing time as expansive was related to greater neural responsivity to emotionally-valenced images.

Regression Analyses

Primary Hierarchical Regression Analysis—As shown in Table 2, stronger performances on the cognitive measures were associated with greater average brain responsivity to negative images. Additionally, being female and believing that time is expansive were associated with greater average amplitude in response to negative images. In the hierarchical regression, Trails B was excluded from the analyses because of its overlap with Trails A. Therefore, gender, Rey Delay, Trails A, Rxn Choice, TOL, and FTP were included. As one participant was missing data for Rey Delay and another for Rxn Choice, this analysis began with 51 individuals. The regression was conducted with the cognitive and socioemotional variables entered in the first group and gender in the second (see Table 4). One multivariate outlier with a Studentized residual greater than 2.50 was identified and excluded, resulting in 50 participants in the final analysis.

As a group, the first set of variables significantly predicted the average amplitude of the negative waveform, $F(5, 44) = 3.81, p < .01$. They accounted for 30.2% of the variance in the waveform's average amplitude, a large effect. TOL uniquely accounted for 5.29% of the variance (a small effect). Examining the strength of the part correlations (sr) as shown in Table 4 provides information about the relative contribution of the remaining variables to the overall model. The addition of gender in the second step did not significantly change the predictive ability of the variables, $F_{change}(1, 43) = 3.94, p = .05$.

Overall greater average amplitude of the LPP waveform in response to negative images is predicted by cognitive variables such that better cognitive performances are associated with more neural reactivity to negative information. Executive functions, as measured by TOL, make the largest unique contribution when explaining variability in PzNeg.

Supplementary Mediator Analyses—An individual's time perspective (FTP) was significantly related to his/her negative emotion processing (PzNeg), $F(1, 48) = 5.22, p = .03$, such that increased processing of negative images was associated with viewing time as expansive. The effect was medium-sized, accounting for 9.8% of the variance. As such, follow-up analyses were conducted to determine if this effect could be explained by variance in FTP produced by differences in cognitive ability.

The results of the follow-up analyses are displayed in Table 5. FTP is first regressed on each cognitive variable to determine if variability in cognition can predict variability in time perspective (A). If such a relationship exists, then PzNeg is regressed on the cognitive variable to determine if variability in cognition can predict variability in negative emotion processing (B). Finally, if both relationships are significant then PzNeg is regressed on FTP after controlling for cognition (C). A nonsignificant change suggests that FTP does not make a significant contribution to the predictive ability of the model after controlling for cognition, or that cognition mediates the relationship between time perspective and negative emotion processing.

These follow-up analyses revealed that Rey Delay, Trails A, and TOL each accounted for variability in FTP (A). Specifically, stronger cognitive abilities (i.e., better performance on Rey Delay, Trails A, and TOL tasks) predicted the perception of time as expansive. Likewise, these cognitive variables accounted for variability in PzNeg (B). Finally, in each analysis, controlling for the variability in PzNeg associated with the cognitive variable eliminated the contribution of FTP to the model (C). As such, these cognitive variables mediated the relationship between time perspective and negative emotion processing.

Discussion

A thorough body of literature suggests that older adults prioritize emotionally positive over negative information, resulting in so-called “positivity effects” in attention, memory, and brain function more generally. The potential role that older adults’ cognitive function plays in this context has been investigated recently, with preliminary indications that available cognitive resources may be voluntarily engaged to allow the expression of positivity effects (Isaaccowitz et al., 2009; Knight et al., 2007). Alternatively, it has been argued that decreased processing of emotional information (particularly negative information) may be an unintended consequence of specific neurobiological changes associated with old age (Ruffman et al., 2008). To address this issue, the current study explored the relationships between various cognitive abilities and neural responsivity to select emotional images within a sample of older adults. A measure of time perspective was included to explore whether the well-established correlation between time perspective and emotion processing may be mediated by cognitive ability.

For the specific measure employed here (the LPP waveform), our results are most consistent with the neurobiological explanation (but see “Summary and Conclusions” below). Individuals displaying more intact cognitive functioning exhibited greater neural activity in response to selected negative emotional images (dead animals). The finding that responsivity to selected positive (appetizing foods) but not neutral images also correlated with cognitive ability (Table 2) provides additional support. That is to say, as a group these findings suggest there is something inherently different about processing the emotional versus non-emotional stimuli used here, and that this difference requires sufficient cognitive involvement for successful processing. Not only did those with stronger cognitive abilities apparently devote more attentional resources toward the negative images, but also the observed correlation between emotional information processing (PzNeg, PzPos) and time perspective (FTP) was contrary to expectations. That is, older adults who experience time as limited were expected to focus on positive, while avoiding negative, information. However, in this study, time perspective correlated positively with neural responses to both positive and negative images. In all cases, viewing time as limited was associated with decreased neural responsivity to emotional information, be it positive or negative.

The supplementary analyses, which explored the relationships between the brain responses to the emotional images, cognitive, and socioemotional measures, also contradicted the socioemotional perspective. For the most part, where time perspective was related to emotion processing, this relationship ceased to exist once the effects of cognitive ability on time perspective were considered. As such, cognitive ability appears to have influenced time perspective, such that individuals who were experiencing weaker cognitive abilities were more likely to view time as restricted. Furthermore, it was the variance associated with this relationship that predicted the relationship between time perspective and responsivity to the negative images.

Interpretation of the present study hinges on the supposition that increased neural activity in response to emotional images reflects enhanced processing of the images. Research has shown that increased activity in the 300 – 900 ms timeframe can be elicited by task-relevant categorizations (Cacioppo, Crites Jr., & Gardner, 1996; Ito & Cacioppo, 2000), as well as emotionally-valenced stimuli (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Schupp et al., 2000). Both have been interpreted as amplified attention to relevant stimuli (Kok, 2001; Lang, Bradley, & Cuthbert, 1997) and researchers have claimed that increased neural activity reflects attention directed to the images to facilitate subsequent processing. In a pivotal study, Ferrari et al. (2008) used an elegant design to separate task-related from motivationally-related effects. They established that both top-down (i.e., task-related) and

bottom-up (i.e., motivational significance) processes affect LPP waveform amplitude, and that these separable effects are additive when task performance is related to the emotional content of the image. Overall, a wealth of research suggests that the amplitude of the LPP waveform reflects neural activity directing attentional resources toward a stimulus to facilitate additional processing of that stimulus (Hajcak, MacNamara, & Olvet, 2010; Schupp, Junghöfer, Weike, & Hamm, 2003).

Given the finding that top-down processing can influence the amplitude of the LPP waveform (Ferrari et al., 2008), one could argue that older adults who are actively regulating their emotions would engage more neural activity in response to negative images. However, research exploring how the LPP waveform is affected by emotion regulation strategies contradicts this argument. Explicitly, studies examining “down-regulation” of response to negatively-valenced stimuli actually revealed *decreased* LPP amplitude when participants were engaged in down-regulation as compared to simple view conditions (Hajcak, Dunning, & Foti, 2009; Moser, Hajcak, Bukay, & Simons, 2006; Moser, Krompinger, Dietz, & Simons, 2009). Given findings in the opposite direction, it seems improbable that the older adults in this study were actively engaged in emotion regulation strategies in response to the negative images.

An effective “negativity bias” for older adults’ neural responses to emotional images was unexpected given previous studies that utilized the same images and found no significant difference between responses to positive and negative images (Kisley et al., 2007; Wood & Kisley, 2006). There are at least two possible explanations. First, the present sample of older adults was more than twice as large as older adult samples in previous studies, thus allowing for detection of smaller effects. Another possible explanation involves the overall cognitive function of the sample in this study compared to previous studies. Although we screened for dementia in previous studies using the MMSE (Kisley et al., 2007; Wood & Kisley, 2006), this instrument has been shown to have questionable sensitivity (Tariq, Tumosa, Chibnall, Perry III, & Morley, 2006). Specifically, when compared against a clinical diagnosis of dementia the MMSE with a cutoff of 26.5 showed sensitivity of .81 for individuals with less than a high school education and .76 for individuals with a high school education or greater. As such, it is possible that our previous studies may have included more individuals with significant memory impairments, characteristic of dementia, than the current study. This may have resulted in the current study population exhibiting more intact cognitive abilities than those of previous studies. This explanation for the observed negativity bias in the current sample would be congruent with the findings of this study, which indicate that individuals who have stronger cognitive abilities are more likely to devote increased neural activity to negative images (see also Figure 2, for which the “normal” group exhibited a stronger negativity bias in neural responses than the “follow up” group).

Summary and Conclusions

The findings of this study suggest that weaker cognitive abilities are predictive of reduced processing of negative information, as measured by neural responses to select emotional images, and that cognitive abilities mediate the relationship between time perspective and this measure of emotion processing. Because a very limited set of emotional images was used here (dead animals, appetizing foods), it remains unclear whether these findings will apply more generally to emotional processing in general. Also, because a younger adult sample was not included, it cannot be determined yet whether the findings here represent age-related effects, or rather whether the observed relationship between cognitive function and brain responses to emotional images apply more generally to the entire adult lifespan. Further research will be required to address these important issues.

The direction of association found here – weaker cognitive abilities correlated with weaker positivity effects in neural responses – directly opposes other recent studies involving behavioral measures of attention allocation. For example, Isaacowitz, Toner, & Neupert (2009) found that older adults with stronger executive function exhibited more pronounced gaze preferences towards positive over negative facial expressions, consistent with the interpretation that older adults may voluntarily allocate their attention towards emotionally positive information in order to improve feelings of well-being. One way to reconcile these discrepant findings is to postulate that there may be at least two routes to a behavioral positivity effect, both related to cognitive function, but related in opposite directions. To explain this idea we propose the dual-route model displayed in Figure 3. In the case of an individual with relatively weaker cognitive abilities, the route would be more direct and the positivity effect should occur in an early phase of emotional processing (e.g., in the brain response to emotional images as captured by the LPP waveform). In this case, the seemingly increased focus on positive information would result from difficulties associated with processing negative information, which would lead the individual to a forced shift in the emotion-processing balance. On the other hand, the individual with relatively stronger cognitive abilities would exhibit two phases to emotion processing, the second of which would be expected to lead to the positivity effect. In the early phase of emotion processing this older adult is expected to process emotional information like a younger adult, focusing more of his/her processing resources on negative information. However, in later phases of emotion processing, he/she should engage emotion regulation strategies to purposefully focus more on positive information and less on negative information to assist himself/herself in maintaining a positive mood state, consistent with socioemotional selectivity theory. This route is consistent with other investigations of older adults that have demonstrated relatively balanced prioritization of emotional stimuli initially (i.e., <1000 ms) with subsequent shifts toward positivity effects in attention allocation (Isaacowitz, Allard, Murphy, & Schlangel, 2009; Knight et al., 2007).

In closing, the findings of the present study are not incompatible with the idea that older adults voluntarily focus their attention on positive information to maintain a positive mood state, as this may be true for individuals with relatively intact cognitive abilities. However, those who experience a shift in the emotion processing balance away from negative information through the direct route of weakened cognitive abilities may be at risk for making poor decisions based on a limited understanding of the negative information involved in the decision. As such, it is imperative for investigators to clarify how and when a positivity effect comes to exist and, even more important, when the effect is detrimental versus beneficial. But either way, aging adults may be able to look forward to a future that is relatively more positive.

Acknowledgments

The authors gratefully acknowledge Dr. John Crumlin for screening research participants and Dr. Stacey Wood for commenting on the manuscript. This research was funded by the National Institute on Aging (1 R15 AG037393-01).

References

- Allen JS, Bruss J, Brown CK, Damasio H. Normal neuroanatomical variation due to age: The major lobes and a parcellation of the temporal region. *Neurobiology of Aging*. 2005; 26:1245–1260.10.1016/j.neurobiolaging.2005.05.023 [PubMed: 16046030]
- Basso MR, Bornstein RA, Lang JM. Practice effects on commonly used measures of executive function across twelve months. *The Clinical Neuropsychologist*. 1999; 13:283–292.10.1076/clin.13.3.283.1743 [PubMed: 10726600]

- Baumeister RF, Bratslavsky E, Finkenauer C, Vohs KD. Bad is stronger than good. *Review of General Psychology*. 2001; 5:323–370.10.1037//1089-2680.5.4.323
- Brassen S, Gamer M, Büchel C. Anterior cingulate activation is related to a positivity bias and emotional stability in successful aging. *Biological Psychiatry*. 2011; 70(2):131–137.10.1016/j.biopsych.2010.10.013 [PubMed: 21183158]
- Cacioppo JT, Berntson GG. Relationship between attitudes and evaluative space: A critical review, with emphasis on the separability of positive and negative substrates. *Psychological Bulletin*. 1994; 115:401–423.10.1037/0033-2909.115.3.401
- Cacioppo JT, Crites SL Jr, Gardner WL. Attitudes to the right: Evaluative processing is associated with lateralized late positive event-related brain potentials. *Personality and Social Psychology Bulletin*. 1996; 22:1205–1219.10.1177/01461672962212002
- Calder AJ, Keane J, Manly T, Sprengelmeyer R, Scott S, Nimmo-Smith I, Young AW. Facial expression recognition across the lifespan. *Neuropsychologia*. 2003; 41:195–202.10.1016/S0028-3932(02)00149-5 [PubMed: 12459217]
- Carstensen LL, Isaacowitz DM, Charles ST. Taking time seriously: A theory of socioemotional selectivity. *American Psychologist*. 1999; 54(3):165–181.10.1037//0003-066X.54.3.165 [PubMed: 10199217]
- Carstensen, LL.; Lang, FR. Future Time Perspective scale. 1996. Retrieved November 1, 2007, from Stanford University, Psychology Department, Life-span Development Laboratory Web site: http://www-psych.stanford.edu/%7Elifespan/doc/FTP_english.pdf
- Carstensen LL, Mikels JA. At the intersection of emotion and cognition: Aging and the positivity effect. *Current Directions in Psychological Science*. 2005; 14(3):117–121.10.1111/j.0963-7214.2005.00348.x
- Charles ST, Mather M, Carstensen LL. Aging and emotional memory: The forgettable nature of negative images for older adults. *Journal of Experimental Psychology: General*. 2003; 132:310–324.10.1037/0096-3445.132.2.310 [PubMed: 12825643]
- Codispoti M, Ferrari V, Bradley MM. Repetition and event-related potentials: Distinguishing early and late processes in affective picture perception. *Journal of Cognitive Neuroscience*. 2007; 19:577–586.10.1162/jocn.2007.19.4.577 [PubMed: 17381249]
- Coman E, Moses JA Jr, Kraemer HC, Friedman L, Benton AL, Yesavage J. Geriatric performance on the Benton Visual Retention Test: Demographic and diagnostic considerations. *The Clinical Neuropsychologist*. 1999; 13:66–77.10.176/clin.13.1.66.1972 [PubMed: 10937649]
- Cuthbert BN, Schupp HT, Bradley MM, Birbaumer N, Lang PJ. Brain potentials in affective picture processing: Covariation with autonomic arousal and affective report. *Biological Psychology*. 2000; 52(2):95–111.10.1016/S0301-0511(99)00044-7 [PubMed: 10699350]
- Davis, HP.; Keller, FR. Colorado Springs: Colorado Assessment Tests. 1998. Colorado Assessment Test manual.
- Delaney RC, Prevey ML, Cramer J, Mattson RH. Test-retest comparability and control subject data for the Rey-Auditory Verbal Learning Test and the Rey-Osterrieth/Taylor Complex Figures. *Archives of Clinical Neuropsychology*. 1992; 7:523–528.10.1093/arclin/7.6.523 [PubMed: 14591403]
- Ferrari V, Codispoti M, Cardinale R, Bradley MM. Directed and motivated attention during processing of natural scenes. *Journal of Cognitive Neuroscience*. 2008; 20:1753–1761.10.1162/jocn.2008.20121 [PubMed: 18370595]
- Hajcak G, Dunning JP, Foti D. Motivated and controlled attention to emotion: Time-course of the late positive potential. *Clinical Neurophysiology*. 2009; 120:505–510. 10.1016/j.clinph.2008.11.028. [PubMed: 19157974]
- Hajcak G, MacNamara A, Olvet DM. Event-related potentials, emotion, and emotion regulation: An integrative review. *Developmental Neuropsychology*. 2010; 35:129–155.10.1080/87565640903526504 [PubMed: 20390599]
- Isaacowitz DM, Allard ES, Murphy NA, Schlangel M. The time course of age-related preferences towards positive and negative stimuli. *Journals of Gerontology - Series B Psychological Sciences and Social Sciences*. 2009; 64:188–192.10.1093/geronb/gbn036

- Isaacowitz DM, Toner K, Neupert SD. Use of gaze for real-time mood regulation: Effects of age and attentional functioning. *Psychology and Aging*. 2009; 24:989–994.10.1037/a0017706 [PubMed: 20025412]
- Isaacowitz DM, Wadlinger HA, Goren D, Wilson HR. Selective preference in visual fixation away from negative images in old age? An eye-tracking study. *Psychology and Aging*. 2006; 21:40–48.10.1037/0882-7974.21.1.40 [PubMed: 16594790]
- Ito TA, Cacioppo JT. Electrophysiological evidence of implicit and explicit categorization processes. *Journal of Experimental Social Psychology*. 2000; 36:660–676.10.1006/jesp.2000.1430
- Ito TA, Larsen JT, Smith NK, Cacioppo JT. Negative information weighs more heavily on the brain: The negativity bias in evaluative categorizations. *Journal of Personality and Social Psychology*. 1998; 75:887–900.10.1037//0022-3514.75.4.887 [PubMed: 9825526]
- Keil A, Bradley MM, Hauk O, Rockstroh B, Elbert T, Lang PJ. Large-scale neural correlates of affective picture processing. *Psychophysiology*. 2002; 39:641–649.10.1111/1469-8986.3950641 [PubMed: 12236331]
- Keith, TZ. *Multiple regression and beyond*. Boston: Pearson Education, Inc; 2006.
- Kensinger EA, Brierly B, Medford N, Growdon JH, Corkin S. Effects of normal aging and Alzheimer's disease on emotional memory. *Emotion*. 2002; 2:118–134.10.1037//1528-3542.2.2.118 [PubMed: 12899186]
- Kisley MA, Wood S, Burrows CL. Looking at the sunny side of life: Age-related change in an event-related potential measure of the negativity bias. *Psychological Science*. 2007; 18:838–843.10.1111/j.1467-9280.2007.01988.x [PubMed: 17760782]
- Knight M, Seymour TL, Gaunt JT, Baker C, Nesmith K, Mather M. Aging and goal-directed emotional attention: Distraction reverses emotional biases. *Emotion*. 2007; 7:705–714.10.1037/1528-3542.7.4.705 [PubMed: 18039037]
- Kok A. On the utility of P3 amplitude as a measure of processing capacity. *Psychophysiology*. 2001; 38:557–577.10.1017/S0048577201990559 [PubMed: 11352145]
- Lang, PJ.; Bradley, MM.; Cuthbert, BN. Motivated attention: Affect, activation, and action. In: Lang, PJ.; Simons, RF.; Balaban, MT., editors. *Attention and orienting: Sensory and motivational processes*. Hillsdale, NJ: Erlbaum; 1997. p. 97-135.
- Lang, PJ.; Bradley, MM.; Cuthbert, BN. Technical Report A-6. Gainesville: University of Florida; 2005. *International Affective Picture System (IAPS): Affective ratings of pictures and instruction manual*.
- Lang FR, Carstensen LL. Time counts: Future time perspective, goals, and social relationships. *Psychology and Aging*. 2002; 17:125–139.10.1037//0882-7974.17.1.125 [PubMed: 11931281]
- Langeslag SJE, van Strien JW. Aging and emotional memory: The co-occurrence of neuophysiological and behavioral positivity effects. *Emotion*. 2009; 9:369–377.10.1037/a0015356 [PubMed: 19485614]
- Leclerc CM, Kensinger EA. Neural processing of emotional pictures and words: A comparison of young and older adults. *Developmental Neuropsychology*. 2011; 34:519–538.10.1080/87565641.2010.549864 [PubMed: 21516546]
- Leigland LA, Schulz LE, Janowsky JS. Age related changes in emotional memory. *Neurobiology of Aging*. 2004; 25:1117–1124.10.1016/j.neurobiolaging.2003.10.015 [PubMed: 15212836]
- Lemay S, Bédard M-A, Rouleau I, Tremblay P-LG. Practice effect and test-retest reliability of attentional and executive tests in middle-aged to elderly subjects. *The Clinical Neuropsychologist*. 2004; 18:284–302. 10/1080/13854040490501718. [PubMed: 15587675]
- Lezak, MD.; Howieson, DB.; Loring, DW. *Neuropsychological assessment*. 4. New York: Oxford University Press; 2004.
- Mather M, Canli T, English T, Whitfield S, Wais P, Ochsner K, Gabrieli John DE, Carstensen LL. Amygdala responses to emotionally valenced stimuli in older and younger adults. *Psychological Science*. 2004; 15:259–263.10.1111/j.0956-7976.2004.00662.x [PubMed: 15043644]
- Mather M, Carstensen LL. Aging and attentional biases for emotional faces. *Psychological Science*. 2003; 14:409–415.10.1111/1467.9280.01455 [PubMed: 12930469]
- Mather M, Carstensen LL. Aging and motivated cognition: The positivity effect in attention and memory. *Trends in Cognitive Science*. 2005; 9:496–502.10.1016/j.tics.2005.08.005

- Mather M, Knight M. Goal-directed memory: The role of cognitive control in older adults' emotional memory. *Psychology and Aging*. 2005; 20:554–570.10.1037/0882-7974.20.4.554 [PubMed: 16420131]
- Mickley Steinmetz KR, Muscatell KA, Kensinger EA. The effect of valence on young and older adults' attention in a rapid serial visual presentation task. *Psychology and Aging*. 2010; 25:239–245.10.1037/a0018297 [PubMed: 20230144]
- Mikels JA, Larkin GA, Reuter-Lorenz PA, Carstensen LL. Divergent trajectories in the aging mind: Changes in working memory for affective versus visual information with age. *Psychology and Aging*. 2005; 20:542–553.10.1037/0882-7974.20.4.542 [PubMed: 16420130]
- Mitrushina, MN.; Boone, KB.; D'Elia, LF. *Handbook of normative data for neuropsychological assessment*. New York: Oxford University Press; 1999.
- Moser JS, Krompinger JW, Dietz J, Simons RF. Electrophysiological correlates of decreasing and increasing emotional responses to unpleasant pictures. *Psychophysiology*. 2009; 46:17–27.10.1111/j.1469-8986.2008.00721.x [PubMed: 18992073]
- Murphy NA, Isaacowitz DM. Preferences for emotional information in older and younger adults: A meta-analysis of memory and attention tasks. *Psychology and Aging*. 2008; 23:263–286.10.1037/0882-7974.23.2.263 [PubMed: 18573002]
- National Institute of Mental Health Center for the Study of Emotion and Attention. *The International Affective Picture System: Digitized photographs*. Gainesville, FL: University of Florida, Center for Research in Psychophysiology; 2001.
- Ochsner KN, Gross JJ. The cognitive control of emotion. *Trends in Cognitive Sciences*. 2005; 9:242–249.10.1016/j.tics.2005.03.010 [PubMed: 15866151]
- Raz, N. Aging of the brain and its impact on cognitive performance: Integration of structural and functional findings. In: Craik, FIM.; Salthouse, TA., editors. *The handbook of aging and cognition*. 2. Mahwah, NJ: Erlbaum; 2000. p. 1-90.
- Rösler A, Ulrich C, Billino J, Sterzer P, Weidauer S, Bernhardt T, Steinmetz H, Frölich L, Kleinschmidt A. Effects of arousing emotional scenes on the distribution of visuospatial attention: Changes with aging and early subcortical vascular dementia. *Journal of Neurological Sciences*. 2005; 229–230:109–116.10.1016/j.jns.2004.11.007
- Ruffman T, Henry JD, Livingstone V, Phillips LH. A meta-analytic review of emotion recognition and aging: Implications for neuropsychological models of aging. *Neuroscience and Behavioral Reviews*. 2008; 32:863–881.10.1016/j.neubiorev.2008.01.001
- Sabatelli D, Lang PJ, Keil A, Bradley MM. Emotional perception: Correlation of functional MRI and event-related potentials. *Cerebral Cortex*. 2007; 17:1085–1091.10.1093/cercor/bhl017 [PubMed: 16769742]
- Salthouse, TA. Steps towards the explanation of adult age differences in cognition. In: Perfect, TJ.; Maylor, EA., editors. *Models of cognitive aging*. Oxford, England: Open University Press; 2000. p. 19-49.
- Schupp HT, Junghöfer M, Weike AI, Hamm AO. Emotional facilitation of sensory processing in the visual cortex. *Psychological Science*. 2003; 14:7–13.10.1111/1467-9280.01411 [PubMed: 12564747]
- Schupp HT, Cuthbert BN, Bradley MM, Cacioppo JT, Ito T, Lang PJ. Affective picture processing: The late positive potential is modulated by motivational relevance. *Psychophysiology*. 2000; 37:257–261.10.1111/1469-8986.3720257 [PubMed: 10731776]
- Sivan, AB. *Benton Visual Retention Test*. 5. San Antonio, TX: Psychological Corporation, Harcourt Brace & Co; 1992.
- StJacques PL, Bessette-Symons B, Cabeza R. Fronto-amygdalar differences during emotional perception and episodic memory. *Journal of the International Neuropsychological Society*. 2009; 15:819–825.10.1017/S1355617709990439 [PubMed: 19703320]
- Tariq SH, Tumosa N, Chibnall JT, Perry MH III, Morley JE. Comparison of the Saint Louis University Mental Status Examination and the Mini-Mental State Examination for detecting dementia and mild neurocognitive disorder—A pilot study. *American Journal of Geriatric Psychiatry*. 2006; 14:900–910.10.1097/01.JGP.0000221510.33817.86 [PubMed: 17068312]

- West RL. An application of prefrontal cortex function theory to cognitive aging. *Psychological Bulletin*. 1996; 120:272–292.10.1037//0033-2909.120.2.272 [PubMed: 8831298]
- Williams LM, Brown KJ, Palmer D, Liddell BJ, Kemp AH, Olivieri G, Peduto A, Gordon E. The mellow years?: Neural basis of improving emotional stability over age. *The Journal of Neuroscience*. 2006; 26:6422–6430.10.1523/JNEUROSCI.0022-06.2006 [PubMed: 16775129]
- Wood S, Kisley MA. The negativity bias is eliminated in older adults: Age-related reduction in event-related brain potentials associated with evaluative categorization. *Psychology and Aging*. 2006; 21:815–820.10.1037/0882-7974.21.4.815 [PubMed: 17201501]

Figure 1.

Grand-averaged waveform of neural activity at site Pz elicited by infrequent positive and negative images, as well as neutral control images, in the context of frequent neutral images. Per current convention, positivity is plotted upward.

Figure 2. Comparison of grand-averaged LPP waveform for the “normal” group (MC1; top) to grand-averaged LPP waveform for the “follow-up” group (MC2; bottom).

Figure 3.

Proposed dual-route model to describe how older adults achieve a positivity effect in emotion processing. Based on this model, the brain process that is captured by the LPP waveform falls within the “Early Stage.”

Table 1

Descriptive Statistics

	N	Min.	Max.	M	SD
Age	53	53	89	68.13	8.72
Education	53	8	23	15.85	2.96
Gender	53	1 (male)	2 (female)	1.66	0.48
Trails A ^a (s)	53	14.87	58.13	31.36	10.80
Trails B ^a (s)	53	30.00	189.37	71.91	27.96
Rey Delay	52	3	15	13.25	2.42
BVRT	53	2	9	5.83	2.05
Rxn. Choice ^a (ms)	52	409	940	569.15	103.01
Rxn. Cond. ^a (ms)	51	2	1758	329.10	391.11
WCST _{cut}	53	1	6	4.55	2.00
WCST _{pers} ^a	53	4	44	16.94	10.67
TOL ^a	53	0	46	9.09	10.16
FTP	53	16	68	40.00	12.84
PosPos	53	0	100	78.49	29.67
PosNeg	53	0	86.67	4.15	15.58
PosNeu	53	0	100	17.04	27.33
NeuPos	53	0	100	39.31	34.21
NeuNeg	53	0	30	4.91	9.05
NeuNeu	53	0	100	55.60	35.98
NegPos	53	0	6.67	0.25	1.10
NegNeg	53	70	100	97.61	5.71
NegNeu	53	0	30	2.01	5.71
PosTime (ms)	53	464.10	2088.80	885.18	288.12
NeuTime (ms)	53	599.79	1442.48	919.20	194.06
NegTime (ms)	53	341.40	1436.23	846.07	255.27
PzPos (μV)	53	-2.81	13.10	5.54	3.11
PzNeu (μV)	53	-.52	11.60	5.39	2.63

	N	Min.	Max.	M	SD
PzNeg (μ V)	53	-2.53	16.57	6.76	4.06

Note. Trails A = basic attention; Trails B = set shifting; Rey Delay = verbal memory; BVRT = visual memory; Rxn Choice = choice reaction time (processing speed); Rxn Cond. = conditional reaction time (inhibition, executive function); WCST_{pers} = perseverative errors/inhibition, executive function; TOL = planning, executive function; FTP = future time perspective; PosPos, PosNeg, PosNeu = percentages of positive, negative, and neutral behavioral responses to positive images, respectively; NeuPos, NeuNeg, NeuNeu = percentage of positive, negative, and neutral behavioral responses to neutral images, respectively; NegPos, NegNeg, NegNeu = percentage of positive, negative, and neutral behavioral responses to negative images, respectively; PosTime, NeuTime, NegTime = average behavioral response time to positive, negative, and neutral images, respectively; PzPos = average amplitude of LPP waveform in response to positive images; PzNeu = average amplitude of LPP waveform in response to neutral images; PzNeg = average amplitude of LPP waveform in response to negative images.

^aHigher scores on these variables represent poorer performance.

Table 2

Correlations of Independent Variables with LPP Amplitudes

	PzPos	PzNeu	PzNeg
Age	-.14	.13	-.14
Education	.01	.20	.03
Gender ^a	.28 *	.22	.29 *
Trails A ^b	-.31 *	-.20	-.35 *
Trails B ^b	-.21	.10	-.37 **
Rey Delay	.20	.15	.30 *
BVRT	.17	.04	.16
Rxn Choice ^b	-.23	.07	-.34 *
Rxn Cond. ^b	-.20	-.21	-.17
WCST _{cat}	.21	.21	.27 *
WCST _{pers} ^b	-.05	-.21	-.04
TOL ^b	-.23	-.14	-.38 **
FTP	.33 *	.20	.31 *

Note. Trails A = basic attention; Trails B = set shifting; Rey Delay = verbal memory; BVRT = visual memory; Rxn Choice = choice reaction time (processing speed); Rxn Cond. = conditional reaction time (inhibition, executive function); WCST_{cat} = switching, executive function; WCST_{pers} = perseverative errors/inhibition, executive function; TOL = planning, executive function; FTP = future time perspective; PzPos, PzNeu, PzNeg = average LPP amplitude at site Pz in response to positive, neutral, and negative images, respectively.

^aGender coding: 1 (*male*), 2 (*female*).

^bHigher scores on these variables represent poorer performance.

*
 $p < .05$.

**
 $p < .01$.

Table 3

Correlation Matrix for Independent Variables

	AG	ED	GE ^a	TA ^b	TB ^b	RD	BV	CH ^b	CO ^b	WC	WP ^b	TO ^b	FT
AG	—	-.09	-.05	.48*	.49*	-.43*	-.43*	.30*	.39*	-.47*	.24	.51*	-.23
ED		—	-.12	-.39*	-.44*	.27	.42*	-.23	-.26	.44*	-.50*	-.19	.17
GE ^a			—	-.19	.03	.41*	-.00	.29*	.07	.18	-.12	-.20	.32*
TA ^b				—	.47*	-.45*	-.38*	.31*	.17	-.51*	.37*	.26	-.31*
TB ^b					—	-.43*	-.51*	.60*	.28*	-.52*	.32*	.38*	-.33*
RD						—	.39*	-.18	-.18	.51*	-.37*	-.47*	.41*
BV							—	-.27	-.16	.51*	-.40*	-.32*	.24
CH ^b								—	.37*	-.29*	.01	.23	-.13
CO ^b									—	-.33*	.19	.48*	-.21
WC										—	-.74*	-.52*	.39*
WP ^b											—	.27*	-.31*
TO ^b												—	-.28*
FT													—

Note. **Bolded** values represent significant correlations < .01. AG = age; ED = education; GE = gender (0 = male, 1 = female); TA = Trails A (basic attention); TB = Trails B (set shifting); RD = Rey Delay (verbal memory); BV = BVRT (visual memory); CH = choice reaction time (processing speed); CO = conditional reaction time (inhibition, executive function); WC = WCST categories completed (switching, executive function); WP = WCST perseverative errors (inhibition, executive function); TO = TOL errors (planning, executive function); FT = future time perspective.

^aGender coding: 1 (male), 2 (female).

^bHigher scores on these variables represent poorer performance.

* $p < .05$

Table 4

Regression Results for Negative Average Amplitude (PzNeg)

Model	B	SE	β	t	p	sr
(Const.)	12.71	4.88		2.61	.01	
Trails A ^b	-.08	.05	-.24	-1.64	.11	-.21
TOL ^b	-.10	.05	-.27	-1.8	.07	-.23
Rey Del.	-.07	.25	-.04	-.27	.79	-.03
Rxn Ch. ^b	-.01	.01	-.18	-1.35	.18	-.17
FTP	.05	.04	.16	1.13	.27	.14

Note. B = Unstandardized coefficient; SE = Standard error; β = Standardized coefficient; sr = Semipartial (part) correlation, bolded values account for >5% of unique variance in PzNeg; Trails A = attention; TOL = executive function; Rey Del. = verbal memory; Rxn Ch. = processing speed; FTP = time perspective.

Table 5

Follow-Up Mediation Analyses

Model	<i>F</i>	<i>p</i>	%	ES
Rey Delay				
A	9.85	<.01	17	M
B	4.81	.03	9.1	M
C	2.33	.13		
Trails A				
A	4.33	.04	8.3	S
B	8.94	<.01	15.7	M
C	2.54	.12		
Rxn Choice				
A	.58	.45		
TOL				
A	5.02	.03	9.5	M
B	9.51	<.01	16.5	M
C	2.31	.14		

Note. A = FTP regressed on cognition; B = PzNeg regressed on cognition; C = PzNeg regressed on FTP after controlling for cognition (*F* is a change statistic for this model); FTP = time perspective; Rey Delay = verbal memory; Trails A = attention; Rxn Choice. = processing speed; TOL = executive function; % = percentage of variance accounted for by model; ES = effect size (S = small, M = medium).