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An ERP investigation of age differences in the negativity bias for self-relevant and non–self-relevant stimuli

Eric C. Fields[a,b,*], Holly J. Bowen[c], Ryan T. Daley[a], Katelyn R. Parisi[a,b], Angela Gutchess[b], Elizabeth A. Kensinger[a]

[a] Boston College, Chestnut Hill, MA, USA
[b] Brandeis University, Waltham, MA, USA
[c] Southern Methodist University, Dallas, TX, USA

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ABSTRACT

As we age, we show increased attention and memory for positive versus negative information, and a key event-related potential (ERP) marker of emotion processing, the late positive potential (LPP), is sensitive to these changes. In young adults the emotion effect on the LPP is also quite sensitive to the self-relevance of stimuli. Here we investigated whether the shift toward positive stimuli with age would be magnified by self-relevance. Participants read 2-sentence scenarios that were either self-relevant or non–self-relevant with a neutral, positive, or negative critical word in the second sentence. The LPP was largest for self-relevant negative information in young adults, with no significant effects of emotion for non–self-relevant scenarios. In contrast, older adults showed a smaller negativity bias, and the effect of emotion was not modulated by self-relevance. The 3-way interaction of age, emotion, and self-relevance suggests that the presence of self-relevant stimuli may reduce or inhibit effects of emotion for non-self-relevant stimuli on the LPP in young adults, but that older adults do not show this effect to the same extent.

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1. Introduction

Not all information that we encounter is processed to the same extent, and the factors that influence which stimuli are prioritized can change with age. In this paper, we present a study using event-related potentials (ERP) to examine how emotional valence and self-relevance affect stimulus prioritization during initial processing and how these processes are affected by age. We begin by discussing valence biases in cognitive processing across the lifespan and how these manifest in ERP. We then discuss the relationship of emotional processing to self-relevance and how self-relevance modulates the neural processes elicited by emotional stimuli, before introducing the present work.

1.1. Age and the positivity effect

A significant body of research suggests that younger adults tend to show increased attention to and better memory for negative stimuli versus positive and neutral stimuli (Baumeister et al., 2001; Rozin and Royzman, 2001; for important exceptions, see Sedikides and Skowronski, 2020). However, there is a shift in attention and memory toward positive stimuli in older age. This change—referred to as the "age-related positivity effect"—can be due to decreased attention and memory to negative stimuli and/or increased attention and memory to positive stimuli, and it can manifest as a decreased negativity bias or as a positivity bias in older participants (Carstensen and DeLiema, 2018; Reed et al., 2014).

There are 2 general approaches to explaining these changes with age. One approach situates the positivity effect in the context of general cognitive and neural decline with age. For example, Cacioppo et al. (2011) argue that the positivity effect may result from decline in functioning of the amygdala, which leads to lower arousal experienced in response to negative stimuli (but not positive or neutral stimuli). The other approach, represented by Socioemotional Selectivity Theory (SST; Carstensen et al., 1999; English and Carstensen, 2017) attributes the positivity effect to changing motivation with age. This theory proposes that as people age, their perception of decreasing future time horizons leads to different motivational goals. In the earlier portions of life, the acquisition of knowledge and self-improvement are particularly important. Under these goals, negative information may be prioritized because it is more relevant to updating knowledge and adapting behavior for the future (see discussion in

* Corresponding author at: Department of Psychology, Boston College, 140 Commonwealth Ave, Chestnut Hill, MA 02467, USA.
E-mail address: eric.fields@bc.edu (E.C. Fields).

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Baumeister et al., 2001; Peeters and Czapinski, 1990). As we age and time horizons are reduced, we instead prioritize emotion regulation to maximize meaningful positive experiences with more immediate payoffs. Thus, the positivity effect is thought to reflect age differences in the motivated processing of emotional information, with older adults prioritizing the processing of positive over negative information.

1.2. ERP investigations of the positivity effect

In the event-related potentials (ERP) literature, the most consistent marker of the additional processing afforded to emotional stimuli is the late positive potential (LPP; Citron, 2012; Hajcak et al., 2012). The LPP is centroparietally distributed, begins around 400 milliseconds to words (often earlier to pictures), and usually lasts at least a few hundred milliseconds. It is generally larger to both negative and positive stimuli than to neutral, but it is also very sensitive to context and to the goals of the participant. For example, as discussed below, non–self-relevant emotional stimuli may fail to modulate the LPP when encountered in a context with self-relevant stimuli. Many studies have shown that the pattern observed on the LPP depends on the task given to participants, demonstrating that the LPP is sensitive not just to the properties of stimuli, but also to the goals of participants (Delaney-Busch et al., 2016; Fields and Kuperberg, 2016; Fischler and Bradley, 2006; Naumann et al., 1997). Perhaps most relevant to Socioemotional Selectivity Theory, several studies have shown that emotion regulation goals modulate LPP amplitude (Speed and Hajcak, 2018). For example, the LPP is reduced to negative pictures when participants are instructed to reduce their emotional reaction (Moser et al., 2006) or when they are told to reappraise images as less negative (Hajcak and Nieuwenhuis, 2006). Importantly, the LPP is also sensitive to individual differences; for example, a number of studies show that the LPP to negative stimuli is larger in those with mood disorders (Speed and Hajcak, 2018).

This combination of features suggests that the amplitude of the LPP reflects the relevance of a stimulus with regard to context- and participant-specific motivational goals (Hajcak and Foti, 2020). This makes the LPP a valuable neural marker for examination of the age-related positivity effect. If the positivity effect arises from age differences in controlled processing in the service of changing motivations with age, this would predict age differences in the LPP to positive versus negative stimuli. Young adults should show a larger LPP to negative than positive stimuli while older adults should show a larger LPP to positive stimuli, or should at least show a reduced LPP to negative stimuli compared to younger adults.

Indeed, several studies have shown a pattern consistent with this prediction. Wood and Kisley (2006) reported a negativity bias on the LPP (negative > positive) for young adults while older adults showed equivalent LPP amplitude to positive and negative (see also Kisley et al., 2007). Langeslag and van Strien (2009) report a similar pattern, but with some evidence of a positivity bias for older adults (see also Meng et al., 2015; Pehlivanoglu and Verhaeghen, 2019). Mathieu et al. (2014) show a negativity bias for both older and young adults when negative stimuli are highly arousing (compared to moderately arousing positive stimuli), but only young adults showed a negativity bias with less arousing negative stimuli. Taken together, these studies suggest that emotional processing as indexed by the LPP is reduced to negative stimuli as people age (but see Renfroe et al., 2016).

1.3. Self-relevance, emotion, and the LPP

Although they have generally been studied separately, self-relevance and emotion have clear overlap. We are most likely to have emotional reactions to events and information that are self-relevant (e.g., Brunyé et al., 2011; Grezes et al., 2013), and the mere fact that we care enough about something for it to produce a strong emotional reaction in some sense makes it self-relevant. Indeed, some theories of emotion propose that stimuli must have some degree of self-relevance to be emotional (Lazarus, 1991). Behaviorally, both self-relevant and emotional stimuli are more likely to be attended to and remembered (Compton, 2003; Cunningham and Turk, 2017; Kensinger and Schacter, 2016; Symons and Johnson, 1997). There is evidence that these enhancements for self-relevance and emotion may be due to partially overlapping neural mechanisms (Gutchess and Kensinger, 2018) and that memory for such stimuli may be better preserved with age than memory for neutral, non–self-relevant stimuli (Kensinger et al., 2014; Kensinger and Gutchess, 2015).

In the ERP literature, self-relevance often elicits a late positivity that is very similar to the LPP seen to emotional stimuli (reviewed in Knyazev, 2013). For example, a larger posterior positivity is seen to participants' own name or face (e.g., Tacikowski and Nowicka, 2010), as well as to self-relevant words (Gray et al., 2004) and objects (Miyakoshi et al., 2007). The impact of self-relevance on the LPP elicited by emotional stimuli has also been examined in a number of studies. These studies have generally shown that the effect of emotion on the LPP is larger for self-relevant stimuli (Fields and Kuperberg, 2016; Herbert et al., 2011a, 2011b; Li and Han, 2010; Pinheiro et al., 2016; Schindler et al., 2014; Shestyuk and Deldin, 2010; but see Fields and Kuperberg, 2012). Interestingly, most of these studies fail to show an emotion effect (negative/positive > neutral) for non–self-relevant stimuli, even while using stimuli that have been shown to generate an emotion effect in other studies. This highlights the context sensitivity of the LPP and suggests that non–self-relevant emotional stimuli may not be prioritized for processing when more motivationally relevant self-relevant emotional stimuli are present in the environment (see Section 4 of this paper and Fields and Kuperberg, 2016).

1.4. The present study

Summarizing the literature reviewed above, the LPP that is commonly observed to emotional stimuli is modulated by self-relevance and may be a marker of a shared mechanism that leads to enhanced processing for both emotional and self-relevant stimuli. This shared mechanism may be relatively well-preserved with age, accounting for the fact that memory declines less for socioaffective stimuli with age. It has also been established that the LPP is sensitive to motivational differences with age that lead to differential processing of positive versus negative stimuli. However, while a number of previous studies have examined the interaction of self-relevance and emotion on the LPP or the interaction of age and emotion on the LPP, no study to date has examined age, self-relevance, and emotion together using ERPs.

Here we employed a paradigm that has previously shown interactions of self-relevance and emotion on the LPP in younger adults (Fields and Kuperberg, 2012, 2016) to compare the pattern of this interaction for younger and older adults. Participants read 2-sentence scenarios with a neutral, positive, or negative outcome in the second sentence. Self-relevance was varied by changing the subject of the second sentence from a person's name to "you." For example: "A man knocks on *Sandra's/your* hotel room door. *Sandra/You* see(s) that he has a tray/gift/gun in his hand." This design is based on research showing that sentences in the second person lead to mental models built from the reader's own perspective (Brunyé et al., 2009, 2011, 2013). ERPs were recorded to the neutral, positive, or negative critical word (underlined in the preceding example) in the second sentence.

We expected that older and younger adults would show differences in how they processed positive versus negative words, with younger adults (but not older) showing larger LPP amplitude to negative words than positive words. This would be consistent with a number of previous ERP studies and a large behavioral literature as reviewed above. Our primary question in the present work was whether this pattern would be modulated by self-relevance. Given that the positivity effect is theorized to emerge largely from motivational factors, we might expect that valence differences across age are particularly pronounced for self-relevant stimuli. More specifically, if the negativity bias in young adults serves the goal of knowledge acquisition as proposed by SST, it should be particularly large for self-relevant stimuli, which are the stimuli that it would be most important to learn. A similar effect may be expected for the positivity effect in older adults, with a particular bias toward self-relevant positive stimuli, as these are the stimuli that are most relevant for emotional well-being.

2. Methods

2.1. Participants

Participants were 51 young adults (18–31 years old) and 48 older adults (60–86 years old) recruited from paper fliers and electronic advertisements posted throughout the greater Boston area and by contacting individuals who had asked to be informed of new studies in our laboratory. Of these, data from 8 young adult participants and 8 older adult participants were unusable due to excessive EEG artifact (>25% of trials rejected; see description of artifact procedures below) or technical problems with the EEG recording. This left 43 young (24 female) and 40 older (26 female) participants included in all results reported below. Participants were administered a battery of cognitive tests, the results of which are presented in the Supplementary Materials.

2.2. Stimuli

Stimuli were the same as those used in previous studies that have shown interactions between self-relevance and emotion on the LPP in younger adults (Fields and Kuperberg, 2012, 2016). In brief, stimuli consisted of 222 sets of 2-sentence scenarios with Emotion (neutral, positive, and negative) and Self-Relevance (self and other) conditions crossed in a 3 × 2 factorial design. The first sentence introduced a situation involving one or more people, only one of which was specifically named (evenly split between male and female names); this sentence was always neutral or ambiguous in valence. The second sentence continued the scenario and was the same across all emotion conditions except for the critical word, which was pleasant, neutral, or unpleasant. To create the self-condition, the named protagonist was changed to “you.” See Table 1 for examples.

Details of stimulus norms are reported in previous publications (Fields and Kuperberg, 2012, 2015, 2016) and are also summarized in the Supplementary Materials for this manuscript.

2.3. Procedure

2.3.1. Stimulus presentation

Lists were constructed such that each of the 222 scenarios appeared in a different condition in each of 6 lists (thus appearing in all conditions across lists). Each list had 37 trials in each of the 6 conditions. Each participant was randomly assigned to one of the 6 lists, and trial order within a list was fully randomized uniquely for each participant.

Trials were self-paced: each began with the word “READY” until the participant pressed a button to begin the trial. In each trial, the first sentence then appeared in full until the participant pressed a button to advance to the second sentence. The second sentence began with a fixation cross displayed for 500 milliseconds, followed by an interstimulus interval (ISI) of 100 milliseconds, followed by each word presented individually for 500 milliseconds with an ISI of 100 milliseconds (a schematic of stimulus presentation can be seen in Fig. S2 in the Supplementary Materials). Participants were asked to refrain from blinking during the second sentence of each scenario (which contained the critical word), but no restrictions were given for other parts of the trial.

Because there is evidence that the positivity effect is strongest when task constraints are minimal (Reed et al., 2014), participants were given no task during initial stimulus presentation other than to silently read each scenario, but they were told that they would later be answering questions about the scenarios. After the EEG session, participants were given a memory test. This paper is not concerned with memory, but methods and results for the memory test are described in the Supplementary Materials to show that participants read and comprehended the scenarios during the EEG recording and that the manipulations of Valence and Self-Relevance produced expected behavioral effects.

2.3.2. Electroencephalographic recording

EEG was continuously recorded during the encoding session. Data was collected using a BioSemi ActiveTwo EEG system and ActiView v6.05 EEG acquisition software (http://www.biosemi.com/). The EEG was recorded from 32 Ag/AgCl electrodes in an elastic cap placed according to the international 10–20 system.[1] In addition, electrodes below and to the left of the left eye and above and to the right of the right eye were recorded to monitor for blinks and eye movements, and electrodes on each mastoid were recorded to serve as the reference. The EEG signal was amplified, filtered online with a low pass fifth order sinc response filter with a half-amplitude cutoff at 104 Hz, and continuously sampled at 512Hz.

2.4. Data processing and analysis

Code used for data processing can be found on the Open Science Framework page for this project: https://doi.org/10.17605/osf.io/egxbc.

EEG and ERP data processing was conducted in EEGLAB v14.1.1 (https://sccn.ucsd.edu/eeglab/index.php; Delorme and Makeig, 2004) and ERPLAB v6.1.4 (https://erpinfo.org/erplab; Lopez-Calderon and Luck, 2014).

The EEG was first referenced to the average of the 2 mastoid electrodes. Segments of the EEG with more than 10 seconds between event markers (representing breaks in the experiment) were automatically deleted. For each segment of continuous EEG, we removed the DC offset by subtracting the average voltage of the entire segment, then applied a high-pass 2nd-order Butterworth infinite impulse response filter with a half-amplitude cut-off of 0.1 Hz (Kappenman and Luck, 2010; Tanner et al., 2015).

For the purposes of artifact correction, we performed independent components analysis (ICA) using the extended infomax algorithm (Lee et al., 1999). ICA was performed on the continuous EEG (i.e., prior to epoching). Segments of EEG with significant artifact that was not neural, ocular, or muscular in origin were identified via visual inspection and excluded from the data submitted to the ICA training algorithm.

[1] Electrodes were: Fp1, AF3, F7, F3, FC1, FC5, T7, C3, CP1, CP5, P7, P3, Pz, PO3, O1, Oz, O2, PO4, P4, P8, CP6, CP2, C4, T8, FC6, FC2, F4, F8, AF4, Fp2, Fz, Cz.

Table 1
Examples of 2-sentence scenarios in each of the 6 conditions. The critical word is underlined (but did not appear underlined in the actual stimulus lists).

Other			Self		
Neutral	Positive	Negative	Neutral	Positive	Negative
A man knocks on Sandra's hotel room door. She sees that he has a tray in his hand.	A man knocks on Sandra's hotel room door. She sees that he has a gift in his hand.	A man knocks on Sandra's hotel room door. She sees that he has a gun in his hand.	A man knocks on your hotel room door. You see that he has a tray in his hand.	A man knocks on your hotel room door. You see that he has a gift in his hand.	A man knocks on your hotel room door. You see that he has a gun in his hand.
Fletcher writes a poem for a class. His classmates think it is a very intricate composition.	Fletcher writes a poem for a class. His classmates think it is a very beautiful composition.	Fletcher writes a poem for a class. His classmates think it is a very boring composition.	You write a poem for a class. Your classmates think it is a very intricate composition.	You write a poem for a class. Your classmates think it is a very beautiful composition.	You write a poem for a class. Your classmates think it is a very boring composition.
Vince spends time with his relatives over the vacation. This turns out to be a characteristic experience for him in many ways.	Vince spends time with his relatives over the vacation. This turns out to be a wonderful experience for him in many ways.	Vince spends time with his relatives over the vacation. This turns out to be a disastrous experience for him in many ways.	You spend time with your relatives over the vacation. This turns out to be a characteristic experience for you in many ways.	You spend time with your relatives over the vacation. This turns out to be a wonderful experience for you in many ways.	You spend time with your relatives over the vacation. This turns out to be a disastrous experience for you in many ways.
After dinner, Lydia is involved in a discussion. Many of her remarks surprise people.	After dinner, Lydia is involved in a discussion. Many of her remarks impress people.	After dinner, Lydia is involved in a discussion. Many of her remarks hurt people.	After dinner, you are involved in a discussion. Many of your remarks surprise people.	After dinner, you are involved in a discussion. Many of your remarks impress people.	After dinner, you are involved in a discussion. Many of your remarks hurt people.
Carmelo has been in his current job for over a year. He learns that he is getting a transfer this month.	Carmelo has been in his current job for over a year. He learns that he is getting a bonus this month.	Carmelo has been in his current job for over a year. He learns that he is getting a pay-cut this month.	You have been in your current job for over a year. You learn that you are getting a transfer this month.	You have been in your current job for over a year. You learn that you are getting a bonus this month.	You have been in your current job for over a year. You learn that you are getting a pay-cut this month.

We extracted segments from 200 milliseconds before to 1100 milliseconds after all events of interest. The previously obtained ICA solution was applied to the segmented data. Components corresponding to ocular activity (blinks and saccades) were identified via visual inspection and removed (0–4 components per participant). We then used spherical spline interpolation as implemented in EEGLAB to replace channels with bad signal for a significant portion of the experiment. Interpolation was employed for 21 (12 young adults, 9 older adults) out of 83 participants with a maximum of 2 channels (always nonadjacent) interpolated for any given participant.

After independent components were removed and bad channels were replaced, epochs with remaining artifact were identified via artifact detection algorithms implemented in ERPLAB. The parameters of these algorithms (e.g., voltage thresholds) were tailored to each participant via visual inspection of the data, but were consistent across all conditions within each participant. Trials containing a blink or large saccade within the first 200 milliseconds of a trial were rejected even if the artifact was corrected via ICA, as these trials may have a delayed neural response due to the eyes being closed or averted during stimulus presentation. Rejection rates ranged from 0% to 24.8% across participants with an average of 9.9%. Rejection rates did not significantly differ by Self-Relevance, Valence, Group or any interaction of these factors in an ANOVA (all $ps > 0.19$).

Importantly, all artifact correction and rejection procedures that involved experimenter decisions (i.e., removal of data from the ICA training set, which independent components to remove, which electrodes to interpolate, and the parameters for artifact detection algorithms) were determined by an experimenter blind to group membership.

After artifact correction and rejection was completed, trials not marked for artifact were averaged within conditions of interest to form ERPs.

2.4.1. Statistical analysis of ERP data

Recent simulation work has suggested that mass univariate analysis (see description below) provides the best balance of Type I error control, flexibility, and power for analysis of ERP data (see results and discussion in Fields and Kuperberg, 2020). The mass univariate approach is especially useful for the analysis of ERP components with variable timing. This is true of the LPP (Fischler and Bradley, 2006; Hajcak and Foti, 2020), which has been seen to vary by around 100 milliseconds even within the paradigm employed here depending on the task (Fields and Kuperberg, 2016; see also Holt et al., 2009). Also of concern in the present work was the possibility that the timing of effects would differ by age, as has been shown on several ERP components (e.g., Kutas and Iragui, 1998), and as suggested by visual examination of previously reported age effects on the LPP (Langeslag and van Strien, 2009; Meng et al., 2015; Wood and Kisley, 2006). This added uncertainty about timing is yet another reason to prefer a mass univariate approach for within-group analysis (since it allows for a data-driven approach to identifying when effects are present), but it presents a challenge for between-group analyses. Our goal was to test for differences in the amplitude of the LPP across age groups independent of any differences in timing. In a traditional mean amplitude approach, it is possible to simply use different time windows for the 2 groups, but the mass univariate approach tests at each time point individually and independently, so there is no way to compare groups independent of timing differences.

We therefore took a 2-step, hybrid approach. First, we conducted mass univariate analyses to examine the effects of Valence and Self-Relevance within each group. We maximized power in these analyses by using a subset of electrodes and time points where the LPP was likely to appear, but these spatial and temporal choices were broad enough to capture the range of timing and scalp distributions seen in previous work (see below). The results of these mass univariate analyses allowed for a data-driven identification of where and when Valence and Self-Relevance effects were centered within each age group. These results were used to identify ROIs for each group, and the average amplitudes within these ROIs were then used to test for interactions of Valence and/or Self-Relevance with Group.[2]

Within group analyses. Statistical analysis of ERPs was conducted via the Mass Univariate Toolbox (Groppe et al., 2011) and Factorial Mass Univariate Toolbox (Fields, 2019). We used a cluster-corrected mass univariate approach (Groppe et al., 2011; Maris and Oostenveld, 2007). Briefly, this approach consists of conducting an ANOVA independently at each time point and electrode of interest. Clusters are identified as adjacent time points/electrodes with effects surpassing a threshold, and all F values in the cluster are summed to form a cluster mass statistic. A permutation approach is used to estimate the null distribution for this cluster statistic, which is then used to calculate a p value for each cluster. We used the method of data reduction to construct the permutation test for our factorial design (Welch, 1990). Briefly, for each main effect we first averaged across the levels of the other factor, and for the Self-Relevance × Valence interaction we first calculated self—other difference waves for each level of the Valence factor. In all cases, this reduced the design to a one-way ANOVA, which allows for an exact permutation test (for a more detailed description, see the supplementary material for Fields and Kuperberg, 2020).

For all analyses, the F value that would give $p = 0.01$ in an uncorrected parametric test was used as the threshold for cluster inclusion and electrodes within approximately 7.5 cm of each other (assuming a head circumference of 56 cm) were considered neighbors. 100,000 permutations were performed for each test. Statistical analysis was conducted on data low-pass filtered at 10 Hz (half amplitude cut-off, 2nd-order Butterworth infinite impulse response filter) to reduce the impact of high frequency noise and downsampled to 128 Hz (Groppe et al., 2011; Luck, 2014, Ch. 13).

To maximize power (Fields and Kuperberg, 2020), we conducted mass univariate analysis in a subset of electrodes and time points within which the LPP was likely to appear. These analysis parameters were chosen based on previous literature and examination of the aggregated grand average from trials (AGAT): the simple mean of all trials across all conditions and participants, which is an unbiased method of parameter selection (Brooks et al., 2017; Luck and Gaspelin, 2017). All analyses were conducted at a group of midline frontal, central, and parietal electrodes (Fz, FC1, FC2, Cz, C3, C4, CP1, CP2, Pz, P3, P4), reflecting the fact that effects of interest had previously been observed at both frontal and posterior sites. For young adults, a time window of 500–900 milliseconds was used for the LPP. The N400 component that precedes the LPP is known to be delayed with age (Kutas and Iragui, 1998), and visual inspection of previous results suggested that the LPP may also be delayed with age (Langeslag and van Strien, 2009; Meng et al., 2015; Wood and Kisley, 2006). Based on the AGAT and previous results, the LPP was examined in a 550–1000 time window for older adults. We also conducted analyses on the N400 component and exploratory analyses across all time points and electrodes, which are reported in the Supplementary Materials.

Between group analyses. As noted above, results of these mass univariate analyses within each group were used to determine ROIs for between-group comparisons. The mean amplitude in these ROIs was used to examine the interaction of each effect with Age via a Valence × Self-Relevance × Age Group split plot ANOVA calculated in jamovi (https://www.jamovi.org/).

3. Results

Results of the post-EEG memory test, additional ERP analyses, and additional figures are available in the Supplementary Materials. Full results of all mass univariate analyses can be found on the Open Science Framework page for this project: https://doi.org/10.17605/osf.io/egxbc.

3.1. Young adults

3.1.1. Visual examination and description of ERP results

As shown in Fig. 1, visual examination of the young adult results showed that the LPP was larger to the Self-Negative condition compared to all other conditions at centroparietal sites starting around 400 milliseconds and continuing to the end of the epoch (1100 milliseconds). All other conditions elicited similar LPP amplitude, although there was some evidence of an increased LPP to the Other-Negative condition as well. It should be noted that although there were multiple local peaks within the LPP time window, these are unlikely to represent subcomponents of the LPP: The critical word was always mid-sentence and the following word was presented at 600 milliseconds; thus, the peaks in the LPP time windows are likely the early ERP response to the following word (which was matched across conditions).

3.1.2. Mass univariate analysis

Results of the mass univariate analysis in the LPP time window are shown in Fig. 2. There were significant clusters for the main effect of Self-Relevance from the beginning of the time window to 650 milliseconds ($p = 0.020$) and for Valence ($p < 0.001$) in a cluster that that spanned the full analysis time window (waveforms and scalp maps for main effects are shown in Figs. S3 and S4 in Supplementary Materials).

There was also a significant cluster for the interaction effect from 604 to 650 milliseconds ($p = 0.024$). We followed-up the interaction effect by examining the effect of Valence within the Other and Self conditions separately (see Figs. S5 and S6 in the Supplementary Materials). The Valence effect was not significant within the Other condition (all clusters: $p > 0.08$), but was significant in a cluster spanning the entire time window for the Self condition ($p < 0.001$). Further follow-ups within the Self condition revealed that the LPP was larger to the Negative condition compared to the Positive ($p < 0.001$) and Neutral ($p < 0.001$) conditions, which did not significantly differ (no clusters found).

3.2. Older adults

3.2.1. Visual examination and description of ERP results

As shown in Fig. 1 (and Figs. S7 and S8 in the Supplementary Materials), visual inspection of the ERPs showed an effect of Valence with both Positive and Negative scenarios eliciting a larger LPP at centroparietal sites starting around 500 milliseconds and continuing to the end of the epoch. There was also a smaller effect of Self-Relevance with Self scenarios eliciting a larger LPP from around 300 milliseconds to 1000 milliseconds at right central sites. These effects appeared to be largely additive rather than interacting.

[2] Because higher-order interactions are statistically orthogonal to lower-order effects in Type III sums of squares ANOVA, this approach does not inflate Type I error rates for the interaction tests if the null is true. However, on the assumption that any interaction between Group and Valence and/or Self-Relevance will consist of modulation of the neural process(es) that show effects of these factors within each group, this approach maximizes power by tailoring the ROIs to best capture these neural processes.

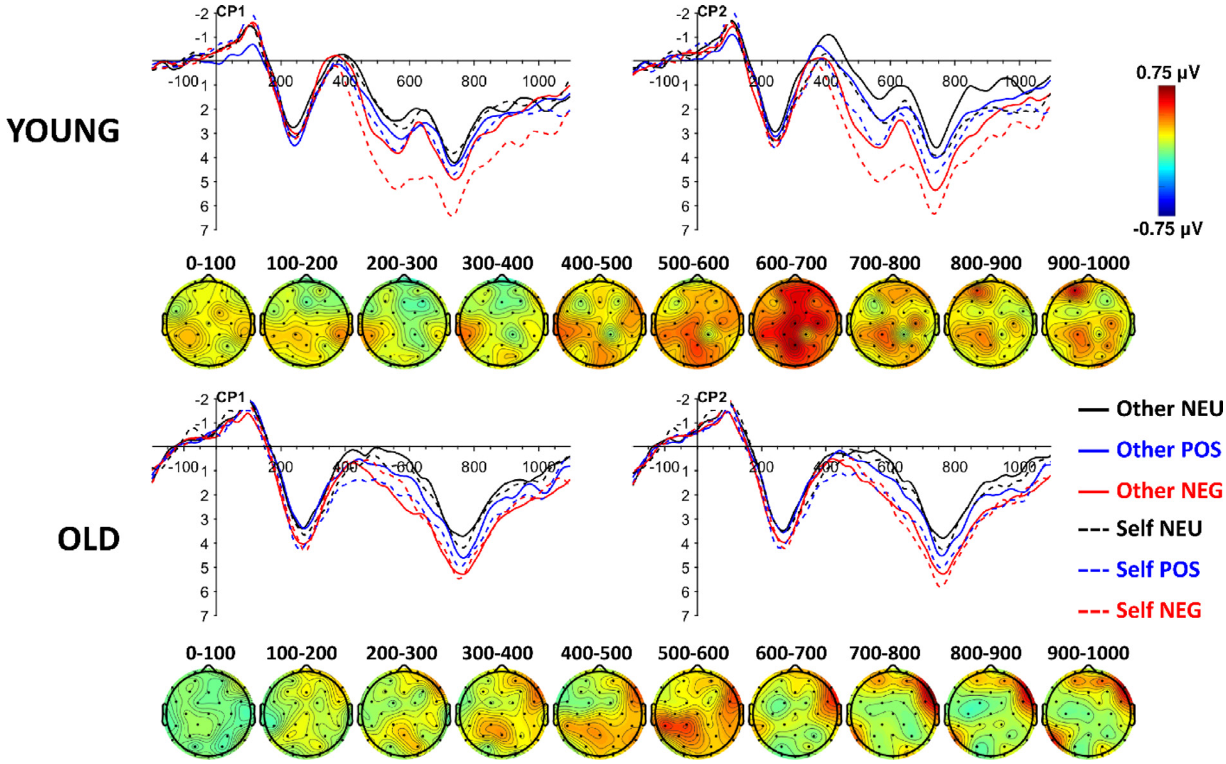

Fig. 1. ERP results. Waveforms show all 6 conditions for each age group separately at posterior sites where the LPP is usually largest. Scalp maps show the standard deviation of the Self-Other difference wave across the 3 valence conditions (i.e., the numerator of the Cohen's *f* effect size for the interaction effect) calculated from the mean amplitude in 100 milliseconds time windows. Figures showing main effects in each group and follow-ups for the Self-Relevance × Valence interaction in young adults are available in the Supplementary Materials.

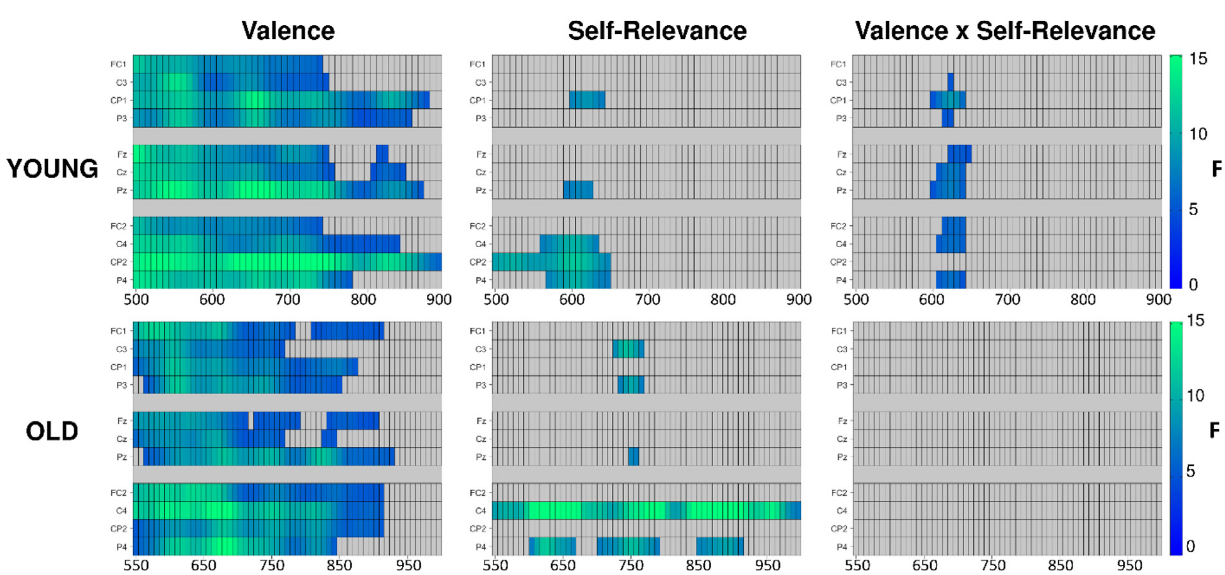

Fig. 2. Mass univariate analysis of ERP data. Time point/electrode combinations not included in a significant cluster are in gray. For locations included in a cluster, the color represents *F* statistic at that location. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

3.2.2. Mass univariate analysis

Results of the mass univariate analysis in the LPP time window are shown in Fig. 2. There was a significant cluster for the main effect of Valence from the beginning of the time window to 932 milliseconds ($p < 0.001$). Follow-up analyses showed that both the Negative ($p < 0.001$) and Positive conditions (2 clusters: $p = 0.005$ and $p = 0.031$) elicited a larger LPP than the Neutral condition for most of the time window at a broad range of electrodes. In addition, the Negative condition elicited a larger LPP than the Positive condition from 588 to 807 milliseconds ($p = 0.019$). There was also a significant cluster for the main effect of Self-Relevance that spanned the entire time window at a set of midline and right central and parietal electrodes ($p = 0.005$).

In contrast to the results seen in young adults, the Self-Relevance × Valence interaction was not significant in older adults (one cluster: $p = 0.299$). Follow-up tests of the effect of Valence

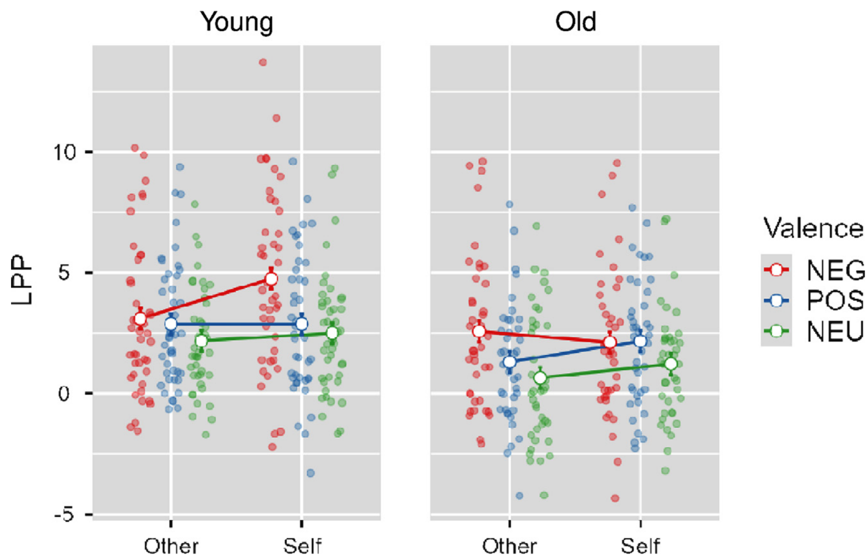

Fig. 3. Valence × Self-Relevance × Age interaction on the LPP. Plotted is the amplitude (μV) averaged across CP1 and CP5 from 550 to 650 milliseconds (see the text). Error bars show the standard error of the mean. Dots show individual participants' amplitude for each condition.

separately in the self and other conditions confirmed that, unlike the young adults, older adults showed significant effects of valence in both conditions (both *ps* = 0.001; see Figs. S9 and S10 in the Supplementary Materials).

3.3. Interactions of self-relevance and valence with age

To examine interactions with Age Group, mean amplitudes were calculated from ROIs determined from the mass univariate analyses within each group (see Section 2). These mean amplitudes were submitted to an Age × Self-Relevance × Valence ANOVA. The Greenhouse-Geisser correction was applied to the degrees of freedom for all analyses. Generalized omega squared ($\omega_G{}^2$) is reported as a measure of effect size (Olejnik and Algina, 2003). For the purposes of calculating $\omega_G{}^2$, age was not considered a measured factor so that results are comparable to studies examining only one age group.

The main effects of Valence and Self-Relevance on the LPP were largest at CP2 for young adults and C4 for older adults. As these are adjacent electrodes and the scalp distributions were generally similar, we simply averaged these 2 electrodes for both groups. To account for the delayed effects for older adults, we used a time window of 500–900 milliseconds for the young participants and 600–1000 milliseconds for the older participants. The ANOVA showed that Age did not significantly modulate the effect of Self-Relevance [$F(1, 81) = 0.04$, $p = 0.839$, $\omega_G{}^2 = -0.001$] or Valence [$F(1.94, 157.48) = 0.59$, $p = 0.553$, $\omega_G{}^2 = -0.001$].

For young adults, the Self-Relevance × Valence interaction on the LPP was largest at CP1 and CP5 from 604 to 650 milliseconds. This interaction was not significant for older adults, so we identified the largest nonsignificant cluster. This cluster was also centered at CP1 and CP5 (see scalp maps in Fig. 1) and spanned 549–596 milliseconds. We therefore examined the Age Group × Self-Relevance × Valence interaction at CP1 and CP5 in a time window of 550–650 milliseconds.[3] These data are shown in Fig. 3. The ANOVA showed a significant Age Group × Self-Relevance × Valence interaction [$F(1.99, 161.59) = 9.59$, $p < 0.001$, $\omega_G{}^2 = 0.012$]. This analysis confirmed that the difference in the Self-Relevance × Valence interaction revealed in the within-subject analyses above is statistically significant.

The within-group analyses reported above serve as one way to break down the pattern driving the 3-way interaction. To examine whether the positivity effect differed by Self-Relevance, we also examined the Age × Valence interaction separately for other-relevant and self-relevant scenarios. There was an Age × Valence interaction for the Self-Relevant scenarios [$F(1.96, 158.35) = 7.64$, $p < 0.001$, $\omega_G{}^2 = 0.017$], but not the Other-Relevant scenarios [$F(1.96, 158.33) = 2.01$, $p < 0.139$, $\omega_G{}^2 = 0.004$]. Within the Self-Relevant scenarios, Welch's *t*-tests revealed that the Negative - Neutral [$t(78.97) = 2.53$, $p = 0.014$] and Negative – Positive [$t(80.72) = 3.76$, $p < 0.001$] contrasts were significantly larger for young adults, whereas the Positive - Neutral contrast did not differ by Age [$t(81) = -1.22$, $p = 0.228$]. That is, the Age × Valence interaction within Self-Relevant scenarios was driven by the particularly large LPP to Self-Negative stimuli in young adults.

4. Discussion

We conducted a study examining the effect of self-relevance and emotional valence on the processing of social vignettes in younger and older adults. The results showed that the late positive potential (LPP) was particularly large for the self-relevant negative scenarios for young adults. In contrast, older adults showed a smaller negativity bias on the LPP and the effect of valence did not differ by self-relevance. We begin by discussing the findings in young adults in comparison to the previous literature, then we discuss the differences observed in older adults.

[3] Readers accustomed to traditional mean time window approaches to the analysis of ERP may note that the time windows showing the interaction effect and the time windows used for the between-group comparison are relatively short, especially for the LPP. As shown by simulations and discussed in detail in Fields and Kuperberg (2020), mass univariate methods tend to underestimate the time course of effects. That a cluster extends across a given time window tells us that there is an effect in that time window, but not that there is no effect outside that time window. This is a weakness that mass univariate methods share with traditional analysis: that an effect is significant when averaged across 300-500ms does not tell us that the effect is present at all time points in that window or that it is absent at points outside that window. For the between-group follow-ups, our goal was to maximize power to detect any interaction, not to characterize the duration of the effect; thus, we were satisfied to use a shorter time window where the within-group analyses revealed the strongest effect.

4.1. A negativity bias modulated by self-relevance in younger adults

Young adults showed a larger LPP to negative than to positive or neutral scenarios, and this effect was larger for self-relevant stimuli. That self-relevant stimuli would have a larger emotional impact is consistent with previous ERP studies examining the interaction of self-relevance and emotion on the LPP (Fields and Kuperberg, 2016; Herbert et al., 2011a, 2011b; Li and Han, 2010; Pinheiro et al., 2016; Schindler et al., 2014; Shestyuk and Deldin, 2010). It is also consistent with the proposal from Socioemotional Selectivity Theory (SST) that valence biases are related to motivational goals and that the negativity bias serves a goal of knowledge acquisition: self-relevant information is surely the most important information for us to learn.

Like most of the previous studies examining self-relevant emotional stimuli in young adults, the effect of emotion on the LPP did not reach significance for the other-relevant scenarios. This contrasts with a large literature showing large effects of emotion on non–self-relevant stimuli when self-relevant stimuli are not included in the study (reviewed in Citron, 2012; Hajcak et al., 2012; Olofsson et al., 2008), including a study with stimuli very similar to the other-relevant stimuli used here (Holt et al., 2009). This highlights the context sensitivity of the LPP: apparently, when self-relevant stimuli are common in the experimental context, non–self-relevant stimuli are less likely to draw the additional processing reflected by the LPP, even when they are emotional.

A number of theoretical frameworks propose that enhanced processing for motivationally relevant stimuli, such as those that are emotional and/or self-relevant, is achieved, at least in part, via inhibition of processing of competing stimuli. For example, this is the core idea of Mather and Sutherland's (2011) arousal-biased competition model, which proposes that emotional arousal serves to enhance processes by which some stimuli are selected for processing at the expense of other stimuli that are inhibited, because neural processing is fundamentally competitive (see also Mather et al., 2016). In the ERP literature both the P300, which is often thought to be closely related to the LPP (Fields and Kuperberg, 2016; Hajcak and Foti, 2020), and the LPP itself have been linked to such inhibitory processes (Brown et al., 2012; Polich, 2007). Inhibition is often invoked to explain effects seen with directly competing stimuli, such as when emotional stimuli draw overt attention at the expense of neutral stimuli (Nummenmaa et al., 2006) or when emotional stimuli are remembered at the expense of neutral backgrounds (Kensinger et al., 2007). However, similar effects can be seen across trials: attention and memory can be impaired for neutral stimuli presented before and after emotional stimuli (Schmidt and Schmidt, 2016; Weinberg and Hajcak, 2011), and memory is worse for neutral stimuli when they are presented in lists mixed with emotional stimuli than when they are presented in neutral-only lists (e.g., Barnacle et al., 2018; Talmi et al., 2007; Watts et al., 2014).

Our results and those of previous studies suggest that the modulation of the emotion effect on the LPP by self-relevance may follow a similar pattern. Although these results have often been framed as self-relevance enhancing the effect of emotion, it seems more accurate to say that the presence of self-relevant scenarios in the experimental context inhibits the effect of emotion in non–self-relevant scenarios (see also discussion in Fields and Kuperberg, 2016).

4.2. A positivity effect with no modulation by self-relevance in older adults?

Older adults also showed the largest LPP to negative stimuli overall, but the difference between negative and positive was smaller in this group and, unlike young adults, older adults additionally showed an increased LPP for positive compared to neutral words. These results appear consistent with the literature on the positivity effect and previous ERP studies examining the effects of age on the LPP (Kisley et al., 2007; Langeslag and van Strien, 2009; Mathieu et al., 2014; Meng et al., 2015; Pehlivanoglu and Verhaeghen, 2019; Wood and Kisley, 2006). However, the interaction of Age and Valence was not statistically significant; instead, only the full Age × Valence × Self-Relevance interaction was significant. Follow-ups suggested 2 ways of looking at this interaction.

One way of summarizing the pattern driving the 3-way interaction is that there was there was an Age × Valence interaction for the self-relevant scenarios, but not the other-relevant scenarios. Within the self-relevant scenarios, this interaction was driven by a particularly large LPP to the negative condition in young adults. This is generally in line with our prediction that the positivity effect (in this case, seen as a reduction in the negativity bias) would be larger for self-relevant stimuli. However, we did not necessarily expect the lack of positivity effect for the other-relevant stimuli, as several previous studies showing the positivity effect on the LPP did not use self-relevant stimuli.

Some insight into the LPP response to the other-relevant scenarios may be gained from the other way of summarizing the 3-way interaction: self-relevance did not modulate the effect of valence in older adults, in contrast both to the present results in younger adults and to the results in several previous studies in younger adults as reviewed above. As can be seen in Figs. 1 and 3 (see also Figs. S9 and S10 in the Supplementary Materials), older adults did show some evidence of an interaction in approximately the same time window and spatial location as the interaction observed for younger adults, and the pattern was consistent with predictions related to the positivity effect: the LPP to positive and neutral scenarios increased with self-relevance while the LPP to negative scenarios decreased with self-relevance. But this modulating effect of self-relevance was clearly smaller for older adults: the interaction of self-relevance and valence did not reach significance for this group, and, in contrast to the young adults, the effect of valence was separately significant for both other and self conditions.

As noted above, a large literature suggests that the other-relevant stimuli would elicit an emotion effect on the LPP in young adults if self-relevant stimuli were not part of the broader context, so it seems that younger adults de-prioritize, or inhibit, non–self-relevant emotional stimuli when more salient self-relevant emotional stimuli are present in the broader context. Following from this interpretation of the young adult data, one explanation of the 3-way interaction we observed is that older adults fail to adjust their goals based on the broader experimental context; that is, they simply processed the non–self-relevant scenarios the same way they would if there were not self-relevant scenarios in the stimulus set. This may be because they do not develop such context-dependent goals, or because they struggle to implement them. If the interaction effect seen in young adults reflects *inhibition* of the LPP effect in non–self-relevant stimuli, an attenuated interaction in older adults would be consistent with research and theory suggesting that many deficits that arise with aging can be explained by reduced capacity for inhibition (Hasher and Zacks, 1988; Lustig et al., 2007; but see Rey-Mermet and Gade, 2018). Support for this idea comes from a recent study where younger and older adults showed similarly sized emotion effects on the LPP when images were task-relevant, but young adults showed greater suppression of the LPP to emotional images when these images were distractions from the main task (Pehlivanoglu and Verhaeghen, 2019).

4.3. Open questions and future directions

On the current evidence, our explanation of the 3-way interaction of age, self-relevance, and valence remains speculative. Although several previous studies have reported a pattern similar to what we report for the young adults, this is the first study examining the interaction of self-relevance and valence in older adults. It will therefore be important for future research to examine whether older adults consistently fail to show modulation of the emotion effect on the LPP by self-relevance. One alternative explanation of our results is simply that the self-relevance manipulation was less effective for older adults. However, this possibility seems inconsistent with the full pattern of results: the expected main effects of self-relevance were observed for both the LPP and the memory data (see Supplementary Materials) in older adults, and there was no evidence that these effects of self-relevance differed meaningfully by group ($\omega_G{}^2 < 0.001$ for all Age × Self-Relevance interactions). These findings are consistent with previous literature showing that self-related biases in perception, attention, and memory generally do not decline with age (Gutchess et al., 2007a, 2007b; Hamami et al., 2011; Hess, 2014; Mattan et al., 2017).

Another interesting question relates to valence effects in younger adults. While the negativity bias we observed in young adults is consistent with a large literature showing a general bias to negative stimuli in this age group (Baumeister et al., 2001; Carstensen and DeLiema, 2018; Rozin and Royzman, 2001), not all previous ERP studies have shown a larger LPP to negative stimuli. This includes studies examining self-relevant stimuli (Herbert et al., 2011a; Pinheiro et al., 2016; Shestyuk and Deldin, 2010). This is likely due in part to variability in the stimuli employed (for comparison of positive and negative pictures from different categories, see Franken et al., 2008; Weinberg and Hajcak, 2010), but previous studies using the same stimuli as the present work have also shown mixed evidence for the negativity bias (Fields and Kuperberg, 2012, 2016).

It is not entirely clear what accounts for this variability, but the task given to participants may be one important factor. Carstensen and colleagues have argued that age differences in valence biases are most likely to be seen when the experimental task does not impose its own goals that influence which stimuli are motivationally relevant (Carstensen and DeLiema, 2018; Reed and Carstensen, 2012), and a meta-analysis of relevant studies supported this proposition (Reed et al., 2014). It is also well-established that the LPP is quite sensitive to task-imposed goals (Delaney-Busch et al., 2016; Fields and Kuperberg, 2016; Fischler and Bradley, 2006). In contrast to previous studies using this paradigm, the present study gave participants no active task when reading the scenarios, which is consistent with the idea that the negativity bias in young adults is most likely to emerge under such circumstances. However, it is not clear that task demands can explain all findings in the literature (e.g., Herbert et al., 2011a showed a larger LPP to positive stimuli with no task), and further research will be needed to understand when a negativity bias is seen on the LPP in young adults.

With regard to the age-related positivity effect, it may be informative to examine the effect of age in paradigms where young adults have shown a positivity bias on the LPP. If older adults show an even larger positivity bias, this would suggest that these are simply paradigms where the positive stimuli are more salient than the negative stimuli (either inherently, or in relation to the task and context). If, on the other hand, the age-related shift is eliminated in these paradigms, it would suggest additional factors need to be taken into account to fully understand effects of valence and age on the LPP.

4.4. Summary and conclusions

The present work extends previous findings showing that differences in the processing of stimuli of differing valence across the lifespan can be seen on a basic neural marker of prioritized processing for emotional stimuli, the LPP. We observed a negativity bias in young adults that was reduced in older adults, as seen in previous studies. However, main effects of Valence did not interact with age; instead, only the full 3-way interaction of Self-Relevance, Valence, and Age was significant. This interaction was driven by a positivity effect for self-relevant scenarios that was not seen on other-relevant scenarios, and by the fact that only the young adults showed a clear modulation of the emotion effect by self-relevance. At present, it is not clear what accounts for this lack of interaction in the older adults, and it will need to be replicated in future work, but an intriguing possibility is that is has more to do with failure to de-prioritize non–self-relevant emotional stimuli than a failure to increase processing for self-relevant emotional stimuli. In any case, these results touch on a number of important topics in cognitive aging research, and they add to a handful of existing studies to show that the LPP, as a neural marker of prioritized processing, can be useful for understanding motivational and cognitive changes in aging.

Disclosure statement

The authors declare no conflicts of interest.

CRediT authorship contribution statement

Eric C. Fields: Conceptualization, Methodology, Software, Formal analysis, Investigation, Data curation, Writing - original draft, Visualization. **Holly J. Bowen:** Investigation, Writing - review & editing. **Ryan T. Daley:** Investigation, Writing - review & editing, Data curation. **Katelyn R. Parisi:** Investigation, Project administration. **Angela Gutchess:** Conceptualization, Methodology, Writing - review & editing, Supervision, Project administration, Funding acquisition. **Elizabeth A. Kensinger:** Conceptualization, Methodology, Writing - review & editing, Supervision, Project administration, Funding acquisition.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.neurobiolaging.2021.02.009.

References

Barnacle, G.E., Tsivilis, D., Schaefer, A., Talmi, D., 2018. Local context influences memory for emotional stimuli but not electrophysiological markers of emotion-dependent attention. Psychophysiology 55 (4), e13014. doi:10.1111/psyp.13014.

Baumeister, R.F., Bratslavsky, E., Finkenauer, C., Vohs, K.D., 2001. Bad is stronger than good. Rev. Gen. Psychol. 5 (4), 323–370. doi:10.1037/1089-2680.5.4.323.

Brooks, J.L., Zoumpoulaki, A., Bowman, H., 2017. Data-driven region-of-interest selection without inflating Type I error rate. Psychophysiology 54 (1), 100–113. doi:10.1111/psyp.12682.

Brown, S.B.R.E., van Steenbergen, H., Band, G.P.H., de Rover, M., Nieuwenhuis, S, 2012. Functional significance of the emotion-related late positive potential. Front. Hum. Neurosci. 6 (33). doi:10.3389/fnhum.2012.00033.

Brunyé, T.T., Ditman, T., Mahoney, C.R., Augustyn, J.S., Taylor, H.A., 2009. When you and I share perspectives: pronouns modulate perspective taking during narrative comprehension. Psychol. Sci. 20 (1), 27–32. doi:10.1111/j.1467-9280.2008.02249.x.

Brunyé, T.T., Ditman, T., Mahoney, C.R., Taylor, H.A., 2011. Better you than I: Perspectives and emotion simulation during narrative comprehension. J. Cogn. Psychol. 23 (5), 659–666. doi:10.1080/20445911.2011.559160.

Brunyé, T.T., Taylor, H.A., Gardony, A.G., Ditman, T., Giles, G.E. (2013). Pronouns and visual perspective-taking: Two replication attempts. PsyArXiv. https://doi.org/10.31234/osf.io/b5jda.

Cacioppo, J.T., Bernston, G.G., Bechara, A., Tranel, D., Hawkley, L.C., 2011. Could an aging brain contribute to subject well-being? The value added by a social neuroscience perspective. In: Todorov, A., Fiske, S.T., Prentice, D.A. (Eds.), Social Neuroscience: Toward Understanding the Underpinnings of the Social Mind. Oxford University Press, New York, pp. 249–262.

Carstensen, L.L., DeLiema, M., 2018. The positivity effect: a negativity bias in youth fades with age. Curr. Opin. Behav. Sci. 19, 7–12. doi:10.1016/j.cobeha.2017.07.009.

Carstensen, L.L., Isaacowitz, D.M., Charles, S.T., 1999. Taking time seriously: a theory of socioemotional selectivity. Am. Psychol. 54 (3), 165–181. doi:10.1037//0003-066x.54.3.165.

Citron, F.M.M, 2012. Neural correlates of written emotion word processing: a review of recent electrophysiological and hemodynamic neuroimaging studies. Brain Lang. 122 (3), 211–226. doi:10.1016/j.bandl.2011.12.007.

Compton, R.J., 2003. The interface between emotion and attention: a review of evidence from psychology and neuroscience. Behav. Cogn. Neurosci. Rev. 2 (2), 115–129. doi:10.1177/1534582303002002003.

Cunningham, S.J., Turk, D.J., 2017. Editorial: a review of self-processing biases in cognition. Quart. J. Exp. Psychol. 70 (6), 987–995. doi:10.1080/17470218.2016.1276609.

Delaney-Busch, N., Wilkie, G., Kuperberg, G.R., 2016. Vivid: how valence and arousal influence word processing under different task demands. Cogn. Affect. Behav. Neurosci. 16 (3), 415–432. doi:10.3758/s13415-016-0402-y.

Delorme, A., Makeig, S., 2004. EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. J. Neurosci. Methods 134 (1), 9–21. doi:10.1016/j.jneumeth.2003.10.009.

English, T., Carstensen, L.L., 2017. Socioemotional selectivity theory. In: Pachana, N.A. (Ed.), Encyclopedia of Geropsychology. Springer, Singapore, pp. 2222–2227.

Fields, E.C. (2019). Factorial Mass Univariate Toolbox (Version 0.4.0) [Computer software]. https://github.com/ericcfields/FMUT/wiki.

Fields, E.C., Kuperberg, G.R., 2012. It's all about you: an ERP study of emotion and self-relevance in discourse. NeuroImage 62 (1), 562–574. doi:10.1016/J.Neuroimage.2012.05.003.

Fields, E.C., Kuperberg, G.R., 2015. Loving yourself more than your neighbor: ERPs reveal online effects of a self-positivity bias. Social Cogn. Affect. Neurosci. 10 (9), 1202–1209. doi:10.1093/scan/nsv004.

Fields, E.C., Kuperberg, G.R., 2016. Dynamic effects of self-relevance and task on neural processing of emotional words in context. Front. Psychol. 6 (2003). doi:10.3389/fpsyg.2015.02003.

Fields, E.C., Kuperberg, G.R., 2020. Having your cake and eating it too: flexibility and power with mass univariate statistics for ERP data. Psychophysiology 57 (2), e13468. doi:10.1111/psyp.13468.

Fischler, I., Bradley, M., 2006. Event-related potential studies of language and emotion: words, phrases, and task effects. Prog. Brain Res. 156, 185–203. doi:10.1016/S0079-6123(06)56009-1.

Franken, I.H.A., Muris, P., Nijs, I., van Strien, J.W, 2008. Processing of pleasant information can be as fast and strong as unpleasant information: Implications for the negativity bias. Netherlands J. Psychol. 64 (4), 168–176. doi:10.1007/BF03076419.

Gray, H.M., Ambady, N., Lowenthal, W.T., Deldin, P., 2004. P300 as an index of attention to self-relevant stimuli. J. Exp. Social Psychol. 40 (2), 216–224. doi:10.1016/S0022-1031(03)00092-1.

Grezes, J., Philip, L., Chadwick, M., Dezecache, G., Soussignan, R., Conty, L., 2013. Self-relevance appraisal influences facial reactions to emotional body expressions. PLoS ONE 8 (2). doi:10.1371/journal.pone.0055885.

Groppe, D.M., Urbach, T.P., Kutas, M., 2011. Mass univariate analysis of event-related brain potentials/fields I: a critical tutorial review. Psychophysiology 48 (12), 1711–1725. doi:10.1111/j.1469-8986.2011.01273.x.

Gutchess, A.H., Kensinger, E.A., 2018. Shared mechanisms may support mnemonic benefits from self-referencing and emotion. Trends Cogn. Sci. 22 (8), 712–724. doi:10.1016/j.tics.2018.05.001.

Gutchess, A.H., Kensinger, E.A., Schacter, D.L., 2007a. Aging, self-referencing, and medial prefrontal cortex. Social Neurosci. 2 (2), 117–133. doi:10.1080/17470910701399029.

Gutchess, A.H., Kensinger, E.A., Yoon, C., Schacter, D.L., 2007b. Ageing and the self-reference effect in memory. Memory 15 (8), 822–837. doi:10.1080/09658210701701394.

Hajcak, G., Foti, D., 2020. Significance?... Significance! Empirical, methodological, and theoretical connections between the late positive potential and P300 as neural responses to stimulus significance: An integrative review. Psychophysiology 57 (7), e13570. doi:10.1111/psyp.13570.

Hajcak, G., Nieuwenhuis, S., 2006. Reappraisal modulates the electrocortical response to unpleasant pictures. Cogn. Affect. Behav. Neurosci. 6 (4), 291–297. doi:10.3758/Cabn.6.4.291.

Hajcak, G., Weinberg, A., MacNamara, A., Foti, D., 2012. ERPs and the study of emotion. In: Luck, S.J., Kappenman, E.S. (Eds.), The Oxford Handbook of Event-Related Potential Components. Oxford University Press, New York, pp. 441–474.

Hamami, A., Serbun, S.J., Gutchess, A.H., 2011. Self-referencing enhances memory specificity with age. Psychol. Aging 26 (3), 636–646. doi:10.1037/a0022626.

Hasher, L., Zacks, R.T., 1988. Working memory, comprehension, and aging: a review and a new view. Psychol. Learn. Motiv. 22, 193–225. doi:10.1016/S0079-7421(08)60041-9.

Herbert, C., Herbert, B.M., Ethofer, T., Pauli, P., 2011a. His or mine? The time course of self-other discrimination in emotion processing. Social Neurosci. 6 (3), 277–288. doi:10.1080/17470919.2010.523543.

Herbert, C., Pauli, P., Herbert, B.M., 2011b. Self-reference modulates the processing of emotional stimuli in the absence of explicit self-referential appraisal instructions. Social Cogn. Affect. Neurosci. 6 (5), 653–661. doi:10.1093/scan/nsq082.

Hess, T.M., 2014. Selective engagement of cognitive resources: motivational influences on older adults' cognitive functioning. Perspect. Psychol. Sci. 9 (4), 388–407. doi:10.1177/1745691614527465.

Holt, D.J., Lynn, S.K., Kuperberg, G.R., 2009. Neurophysiological correlates of comprehending emotional meaning in context. J. Cogn. Neurosci. 21 (11), 2245–2262. doi:10.1162/jocn.2008.21151.

Kappenman, E.S., Luck, S.J., 2010. The effects of electrode impedance on data quality and statistical significance in ERP recordings. Psychophysiology 47 (5), 888–904. doi:10.1111/j.1469-8986.2010.01009.x.

Kensinger, E.A., Allard, E.R., Krendl, A.C., 2014. The effects of age on memory for socioemotional material: an affective neuroscience perspective. In: Verhaeghen, P., Hertzog, C. (Eds.), The Oxford Handbook of Emotion, Social Cognition and Problem Solving in Adulthood. Oxford University Press, New York, pp. 26–46.

Kensinger, E.A., Garoff-Eaton, R.J., Schacter, D.L., 2007. Effects of emotion on memory specificity: memory trade-offs elicited by negative visually arousing stimuli. J. Mem. Lang. 56 (4), 575–591. doi:10.1016/j.jml.2006.05.004.

Kensinger, E.A., Gutchess, A.H., 2015. Memory for emotional and social information in adulthood and old age. In: Addis, D.R., Barense, M., Duarte, A. (Eds.), The Wiley Handbook on the Cognitive Neuroscience of Memory. Wiley, West Sussex, UK, pp. 427–447.

Kensinger, E.A., Schacter, D.L., 2016. Memory and emotion. In: Feldman Barrett, L., Lewis, M., Haviland-Jones, J.M. (Eds.), Handbook of Emotions. Guilford Press, New York, pp. 564–578.

Kisley, M.A., Wood, S., Burrows, C.L., 2007. Looking at the sunny side of life: age-related change in an event-related potential measure of the negativity bias. Psychol. Sci. 18 (9), 838–843. doi:10.1111/j.1467-9280.2007.01988.x.

Knyazev, G.G., 2013. EEG correlates of self-referential processing. Front. Hum. Neurosci. 7 (264). doi:10.3389/Fnhum.2013.00264.

Kutas, M., Iragui, V., 1998. The N400 in a semantic categorization task across 6 decades. Electroencephal. Clin. Neurophysiol. 108 (5), 456–471. doi:10.1016/S0168-5597(98)00023-9.

Langeslag, S.J.E., van Strien, J.W, 2009. Aging and emotional memory: the co-occurrence of neurophysiological and behavioral positivity effects. Emotion 9 (3), 369–377. doi:10.1037/a0015356.

Lazarus, R.S., 1991. Progress on a cognitive-motivational-relational theory of emotion. Am. Psychol. 46 (8), 819–834. doi:10.1037/0003-066x.46.8.819.

Lee, T.W., Girolami, M., Sejnowski, T.J., 1999. Independent component analysis using an extended infomax algorithm for mixed subGaussian and superGaussian sources. Neural Comput. 11 (2), 417–441. doi:10.1162/089976699300016719.

Li, W., Han, S., 2010. Perspective taking modulates event-related potentials to perceived pain. Neurosci. Lett. 469 (3), 328–332. doi:10.1016/j.neulet.2009.12.021.

Lopez-Calderon, J., Luck, S.J., 2014. ERPLAB: an open-source toolbox for the analysis of event related potentials. Front. Hum. Neurosci. 8 (213). doi:10.3389/Fnhum.2014.00213.

Luck, S.J., 2014. An Introduction to the Event-Related Potential Technique, second ed. The MIT Press, Cambridge, MA.

Luck, S.J., Gaspelin, N., 2017. How to get statistically significant effects in any ERP experiment (and why you shouldn't). Psychophysiology 54 (1), 146–157. doi:10.1111/psyp.12639.

Lustig, C., Hasher, L., Zacks, R.T., 2007. Inhibitory deficit theory: recent developments in a "new view. In: Gorfein, D.S., MacLeod, C.M. (Eds.), Inhibition in Cognition. American Psychological Association, Washington, DC, pp. 145–162.

Maris, E., Oostenveld, R., 2007. Nonparametric statistical testing of EEG- and MEG-data. J. Neurosci. Meth. 164 (1), 177–190. doi:10.1016/j.jneumeth.2007.03.024.

Mather, M., Clewett, D., Sakaki, M., Harley, C.W., 2016. Norepinephrine ignites local hotspots of neuronal excitation: how arousal amplifies selectivity in perception and memory. Behav. Brain Sci. 39, e200. doi:10.1017/S0140525X15000667.

Mather, M., Sutherland, M.R., 2011. Arousal-biased competition in perception and memory. Perspect. Psychol. Sci. 6 (2), 114–133. doi:10.1177/1745691611400234.

Mathieu, N.G., Gentaz, E., Harquel, S., Vercueil, L., Chauvin, A., Bonnet, S., Campagne, A., 2014. Brain processing of emotional scenes in aging: effect of arousal and affective context. PLoS ONE 9 (6). doi:10.1371/journal.pone.0099523.

Mattan, B.D., Quinn, K.A., Acaster, S.L., Jennings, R.M., Rotshtein, P., 2017. Prioritization of self-relevant perspectives in ageing. Quart. J. Exp. Psychol. 70 (6), 1033–1052. doi:10.1080/17470218.2015.1127399.

Meng, X.X., Yang, J.M., Cai, A.A., Ding, X.S., Liu, W.W., Li, H., Yuan, J.J., 2015. The neural mechanisms underlying the aging-related enhancement of positive affects: electrophysiological evidences. Front. Aging Neurosci. 7. doi:10.3389/fnagi.2015.00143.

Miyakoshi, M., Nomura, M., Ohira, H., 2007. An ERP study on self-relevant object recognition. Brain Cognit. 63 (2), 182–189. doi:10.1016/j.bandc.2006.12.001.

Moser, J.S., Hajcak, G., Bukay, E., Simons, R.F., 2006. Intentional modulation of emotional responding to unpleasant pictures: an ERP study. Psychophysiology 43 (3), 292–296. doi:10.1111/j.1469-8986.2006.00402.x.

Naumann, E., Maier, S., Diedrich, O., Becker, G., Bartussek, D., 1997. Structural, semantic, and emotion-focussed processing of neutral and negative nouns: event-related potential correlates. J. Psychophysiol. 11 (2), 158–172.

Nummenmaa, L., Hyona, J., Calvo, M.G., 2006. Eye movement assessment of selective attentional capture by emotional pictures. Emotion 6 (2), 257–268. doi:10.1037/1528-3542.6.2.257.

Olejnik, S., Algina, J., 2003. Generalized eta and omega squared statistics: measures of effect size for some common research designs. Psychol. Meth. 8 (4), 434–447. doi:10.1037/1082-989x.8.4.434.

Olofsson, J.K., Nordin, S., Sequeira, H., Polich, J., 2008. Affective picture processing: an integrative review of ERP findings. Biol. Psychol. 77 (3), 247–265. doi:10.1016/j.biopsycho.2007.11.006.

Peeters, G., Czapinski, J., 1990. Positive-negative asymmetry in evaluations: the distinction between affective and informational negativity effects. Eur. Rev. Social Psychol. 1 (1), 33–60. doi:10.1080/14792779108401856.

Pehlivanoglu, D., Verhaeghen, P., 2019. Now you feel it, now you don't: motivated attention to emotional content is modulated by age and task demands. Cogn. Affective Behav. Neurosci. 19 (5), 1299–1316. doi:10.3758/s13415-019-00741-z.

Pinheiro, A.P., Rezaii, N., Nestor, P.G., Rauber, A., Spencer, K.M., Niznikiewicz, M., 2016. Did you or I say pretty, rude or brief? An ERP study of the effects of speaker's identity on emotional word processing. Brain Lang. 153, 38–49. doi:10.1016/j.bandl.2015.12.003.

Polich, J., 2007. Updating P300: an integrative theory of P3a and P3b. Clin. Neurophysiol. 118 (10), 2128–2148. doi:10.1016/j.clinph.2007.04.019.

Reed, A.E., Carstensen, L.L., 2012. The theory behind the age-related positivity effect. Front. Psychol. 3 (339). doi:10.3389/fpsyg.2012.00339.

Reed, A.E., Chan, L., Mikels, J.A., 2014. Meta-analysis of the age-related positivity effect: age differences in preferences for positive over negative information. Psychol. Aging 29 (1), 1–15. doi:10.1037/a0035194.

Renfroe, J.B., Bradley, M.M., Sege, C.T., Bowers, D., 2016. Emotional modulation of the late positive potential during picture free viewing in older and young adults. PLoS ONE (9) 11. doi:10.1371/journal.pone.0162323.

Rey-Mermet, A., Gade, M., 2018. Inhibition in aging: what is preserved? What declines? A meta-analysis. Psychonom. Bull. Rev. 25 (5), 1695–1716. doi:10.3758/s13423-017-1384-7.

Rozin, P., Royzman, E.B., 2001. Negativity bias, negativity dominance, and contagion. Personality Social Psychol. Rev. 5 (4), 296–320. doi:10.1207/S15327957pspr0504_2.

Schindler, S., Wegrzyn, M., Steppacher, I., Kissler, J., 2014. Its all in your head: How anticipating evaluation affects the processing of emotional trait adjectives. Front. Psychol. 5 (1292), 1–10. doi:10.3389/Fpsyg.2014.01292.

Schmidt, S.R., Schmidt, C.R., 2016. The emotional carryover effect in memory for words. Memory 24 (7), 916–938. doi:10.1080/09658211.2015.1059859.

Sedikides, C., Skowronski, J.J., 2020. In human memory, good can be stronger than bad. Curr. Direct. Psychol. Sci. 29 (1), 86–91. doi:10.1177/0963721419896363.

Shestyuk, A.Y., Deldin, P.J., 2010. Automatic and strategic representation of the self in major depression: trait and state abnormalities. Am. J. Psychiatry 167 (5), 536–544. doi:10.1176/appi.ajp.2009.06091444.

Speed, B.C., Hajcak, G., 2018. Event-related potentials and emotion dysregulation. In: Beauchaine, T.P., Crowell, S.E. (Eds.), The Oxford Handbook of Emotion Dysregulation. Oxford University Press, New York.

Symons, C.S., Johnson, B.T., 1997. The self-reference effect in memory: a meta-analysis. Psychol. Bull. 121 (3), 371–394. doi:10.1037/0033-2909.121.3.371.

Tacikowski, P., Nowicka, A., 2010. Allocation of attention to self-name and self-face: an ERP study. Biol. Psychol. 84 (2), 318–324. doi:10.1016/j.biopsycho.2010.03.009.

Talmi, D., Luk, B.T.C., McGarry, L.M., Moscovitch, M, 2007. The contribution of relatedness and distinctiveness to emotionally-enhanced memory. J. Mem. Lang. 56 (4), 555–574. doi:10.1016/j.jml.2007.01.002.

Tanner, D., Morgan-Short, K., Luck, S.J., 2015. How inappropriate high-pass filters can produce artifactual effects and incorrect conclusions in ERP studies of language and cognition. Psychophysiology 52 (8), 997–1009. doi:10.1111/psyp.12437.

Watts, S., Buratto, L.G., Brotherhood, E.V., Barnacle, G.E., Schaefer, A., 2014. The neural fate of neutral information in emotion-enhanced memory. Psychophysiology 51 (7), 673–684. doi:10.1111/psyp.12211.

Weinberg, A., Hajcak, G., 2010. Beyond good and evil: the time-course of neural activity elicited by specific picture content. Emotion 10 (6), 767–782. doi:10.1037/A0020242.

Weinberg, A., Hajcak, G., 2011. The late positive potential predicts subsequent interference with target processing. J. Cogn. Neurosci. 23 (10), 2994–3007. doi:10.1162/jocn.2011.21630.

Welch, W.J., 1990. Construction of permutation tests. J. Am. Stat. Assoc. 85 (411), 693–698. doi:10.2307/2290004.

Wood, S., Kisley, M.A., 2006. The negativity bias is eliminated in older adults: age-related reduction in event-related brain potentials associated with evaluative categorization. Psychol. Aging 21 (4), 815–820. doi:10.1037/0882-7974.21.4.815.