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Emotional Aging and Emotional Attention Bias: Evidence from The MIDUS Refresher Study

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Abstract

Late adulthood is characterized by cognitive but not emotional decline. Some evidence suggests that older adults, compared to younger adults, have an attentional and memory bias towards positive information. Older adulthood is also characterized in functional decline in the lateral prefrontal cortex but functional preservation and enhancement in the ventromedial prefrontal cortex (vmPFC) and amygdala. The current study therefore investigated whether there was an age-related positivity bias in attention and whether this bias was driven by such age-related changes within these three regions of the emotion regulatory network. Emotional attention bias was measured by reaction time differences between negative and positive valence categories of stimuli in the affective Go/no-Go task. Responses within the emotional regulatory network were collected via an fMRI task presenting positive, negative, and emotionally neutral pictures to 100 adults (26 to 76 years old), recruited in the context of the MIDUS study. No age-related emotional attention bias was found. Age was, as expected, found to be negative associated with lateral PFC activation during negative stimuli presentation, but unexpected also negatively associated with such activation in the vmPFC and the amygdala. Finally, emotional attention bias was negatively associated with lateral PFC activation during negative stimuli presentation. These findings contradicted several previous studies and are therefore critically assessed in both methodology and theoretical standing. Future directions are also addressed.

Unlike cognitive aging, emotional experience and functioning have been shown to be maintained and even improved overtime (Mather, 2016; Scheibe & Carstensen, 2010). Across the literature (Mather, 2016; Mather & Carstensen, 2005; Mather & Carstensen, 2005), improvement is qualified as the enhancement of emotional regulation processes, where one reacts less and recovers faster to aversive events, and maintains, prolongs, and is more likely to experience positive affect. Such improvement in older adults is termed the "positivity effect" and has been observed in older adults' attention to (Carstensen & Mikels, 2005; Kessler & Staudinger, 2009; Mather & Carstensen, 2003, 2005; Mather & Carstensen, 2005; Rosler et al., 2005) and memory of (Comblain, D'Argembeau, & van der Linden, 2005; Kennedy et al., 2004; Sakaki & Mather, 2013) emotional stimuli compared to that of younger adults (Mather, 2016; Reed, Chan, & Mikels, 2014). The positivity effect has however not been consistently found in the literature (Denburg, Buchanan, Tranel, & Adolphs, 2003; Grühn, Smith, & Baltes, 2005), as great individual differences were found among older healthy adults (Murphy & Isaacowitz, 2008; Lenehan, Summers, Saunders, Summers, & Vickers, 2016).

The interaction between emotional attention biases and aging, specifically, is under ongoing investigation. Studies have found that older adults, compared to younger ones, either paid more attention to positive information (Mather & Carstensen, 2003; Mather et al., 2005), diverted their attention away from negative stimuli (Rosler et al., 2005), or had no attentional bias towards positive stimuli (Demeyer & de Raedt, 2013; Tomaszczyk & Fernandes, 2014). Whether older adults have an involuntary emotional attention bias towards positive information, or whether age-related differences in attention are the result of deliberate attention allocation is also unclear.

Studying emotional attention bias in the context of the aging brain is also an opportunity to gather insight into a current debate on the neurological underpinnings of the positivity effect in emotion regulation. Of the two emerging views on the topic, one proposes that age-related differences in affective style (i.e. emotional attention biases, effective emotional regulation) are the product of age-related neurostructural or functional changes (Cacioppo, Berntson, Bechara, Tranel, & Hawkley, 2011). The other proposes that older adults have more mood-enhancement goals compared to younger people and are more motivated to implement strategies towards maintaining a positive affect (Carstensen & Mikels, 2005; Mather, 2016; Scheibe & Carstensen, 2010). In this latter view, the positivity effect in attention is the result of slow voluntary cognitive processes to regulate one's attention (Yantis, 2000). While the former provides an account for the observed individual differences in positivity effects (Demeyer & de Raedt, 2013; Murphy & Isaacowitz, 2008), the latter view possibly justifies why the positivity effect in attention has not been found in speed attentional task[1].

Regulating one's reaction to negative stimuli has been associated with the inverse coupling of the ventromedial prefrontal cortex (vmPFC) and amygdala, as increased vmPFC activity predicted decreased amygdala reactivity to aversive stimuli (Etkin, Egner, & Kalisch, 2011; Hartley & Phelps, 2010; Kim, Somerville, Johnstone, Alexander, & Whalen, 2003; Oschner & Gross, 2004; Urry et al., 2006), enabled via strong bi-directional projections between both areas (Ghashghaei, Hilgetag, & Barbas, 2007). Similarly, aversive stimuli and their reappraisal induce activity in several areas

[1] An alternative view, not presently tested, is that if there were a positivity effect in emotion regulatory processes of the elderly, it could be observable in speed-oriented tasks that measure emotional attention if strategic mood-enhancement became habitual in the elderly, to the point of being ingrained and automatically used during passive viewing of emotional stimuli.

within the lateral prefrontal cortex (e.g. ventrolateral PFC, right dorsolateral PFC, rostrolateral PFC; Hartley & Phelps, 2010; Morawetz, Bode, Baudewig, Jacobs, & Heekeren, 2016; Nitschke, Sarinopoulos, Mackiewicz, Schaefer, & Davidson, 2005; Oschner et al., 2002; Urry et al., 2006). Greater connectivity between the prefrontal cortex, particularly the left vmPFC (Jackson et al, 2003; Jacques et al., 2010; Ochsner et al., 2004), and the amygdala was linked to lesser reactions to aversive stimuli. Thus, the emotion regulatory network consists of, in part, top-down regulation of amygdala response to negative stimuli, from several regions of the medial and lateral prefrontal cortex.

Despite inconsistencies (Gunning-Dixon et al., 2003; Nashiro, Sakaki, & Mather, 2011; Samanez-Larkin & Carstensen, 2011; Tessitore et al., 2005, Fjell & Walhovd, 2010), trends emerge in the research on age-related brain changes within the emotion regulatory network. Amygdala volume has been shown to either remain constant with age (Cherbuin et al., 2011; Fjell & Walhovd, 2010) or decline (Allen, Bruss, Brown, & Damasio, 2005; Cacioppo et al., 2011) but many found that amygdala response to aversive or emotional stimuli reduces with age (Mather, 2016; Samanez-Larkin & Carstensen, 2011). In a meta-analysis, Fjell and Walhovd (2010) found that compared to other brain regions, and especially to the lateral PFC where age has been associated with significant structural degradation, cortical thickness and activity level in the vmPFC were preserved overtime. Age was negatively associated with dlPFC or lateral PFC BOLD signal during negative picture viewing (Nashiro, Sakaki, & Mather, 2011) but positively associated with vmPFC and medial PFC BOLD signal (Iidaka et al., 2002; Samanez-Larkin & Carstensen, 2011). In fact, van Reekum and colleagues (2018) found that age

was positively associated with activity in the vmPFC in response to negative stimuli but negatively associated with such activity in the lateral PFC, and that negative stimuli-induced activity in the vmPFC was associated with grey matter probability (GMP) in the lateral PFC. The authors argued that older adults increasingly rely on the medial PFC, as a compensation for decline in lateral PFC functionality, to regulate their emotion and maintain positive affect.

The present study aimed at determining whether the age-related positivity effect occurs without conscious effort to improve or maintain positive affect, by comparing performance on the affective Go/no-Go task between adult younger and older age groups. Indeed, the affective Go/no-Go task is a fast-pace cognitive task designed to detect attention preferences towards negative or positive stimuli, which enables the study of involuntary emotional attention bias. This study also investigated whether age-related differences in brain regions within the emotion regulatory network were similar to those related to emotional attention biases as seen by performance on the affective Go/no-Go task. Doing so partially consisted of replicating previously stated findings by van Reekum and colleagues (2018), that the medial PFC compensates for age-related lessening in lateral PFC functionality during emotion processing.

Previous research has shown that, during the affective Go/no-Go task, lateral PFC regions were recruited when participants were required to only pay attention to negative words while ventral and medial PFC regions were recruited when participants were required to only pay attention to positive words (Casey et al., 1997; Elliott et al., 2000, 2002; Garavan et al., 2002; Ochsner & Gross, 2005). Thus, current hypotheses stated that both age and attention bias towards positive stimuli are negatively associated with lateral

PFC activation during negative picture viewing, positively associated with vmPFC activation and negatively associated with amygdala activation. If a) younger and older adults did not differ in affective Go/no-Go task performance, that is, if older adults did not show more attention bias towards positive stimuli compared to younger adults, and b) if age-related change in amygdala, vmPFC and lateral PFC BOLD signal during negative stimuli presentation were not related with emotional attention bias scores, results would support the view that the age-related positivity effect is rather a product of mood-enhancement goals and strategies associated with older adults. Indeed, in a fast-paced task, participants do not have time to implement mood-enhancement strategies and thus would only show emotional attention biases towards positive stimuli if such biases were involuntary and independent of conscious will.

However, if age was associated attention bias toward positive stimuli and that both age and attention bias scores were positively associated with vmPFC response to negative stimuli while being negatively associated with amygdala and lateral PFC responses, results would support the argument presented by Cacioppo and colleagues (2011) that the positivity effect may be a byproduct of neurobiological aging. Indeed, such associations between age, involuntary emotional attention bias, and differences in brain functionality within the emotional regulatory network would show, for the first time, that the age-related "positivity effect" in attention occurs even under time constraints that make conscious goal implementation unlikely, and that such biases are driven by age-induced neurological change in regions that become differently involved in emotional processing with age.

Method

Participants

Participants were recruited in the context of Midlife in the United States (MIDUS), a longitudinal study of sociopsychological and physiological well-being in adults nationwide (http://www.midus.wisc.edu). In the current study, participants were part of the independent MIDUS Refresher sample, who were recruited via random digit dialing national telephone calls and whose data were collected between 2012 and 2015. A portion of the sample were African-Americans recruited door-to-door in Milwaukee, WI, in an effort to diversify the overall MIDUS Refresher sample. Out of the 138 participants recruited for the neuroscientific portion of MIDUS, 118 participants completed both the functional magnetic resonance imaging (fMRI) task (n = 122) and the Affective Go/no-Go task (AGN; n = 134), including 33 of the African-American participants recruited in Milwaukee. All participants were right handed, passed the MRI compatibility screening, and provided informed consent before every study procedure. The age of the 118 remaining participants ranged from 26 to 76 (*mean* = 48.13 ± 12, *median* = 48.5). After data processing, only 100 participants remained but the new sample's age range and distribution was preserved (*mean* = 47.6 ± 11.69, *median* = 48), with 53 females and 47 males. Age groups were defined using a median split, with younger participants being younger than 48 years old (n = 48) and older participants being 48 years old or older (n = 52).

Experimental Paradigm

The neuroscientific portion of the MIDUS protocol consists of two data collection sessions over the course of two days, during which participants complete the Affective

Go/no-Go task, the fMRI task, and a structural T1 scan, as well as other tasks that are not addressed in this present study.

Affective Go/no-Go task (AGN)

Apparatus

The AGN was presented as part of the Cambridge Neuropsychological Test Automated Battery (CANTAB; Cambridge Cognition, Cambridge, UK; Robbins et al., 1994). The task was administrated on a 12-inch portable Slimbook Panel Touchscreen PC, attached to a two-button press pad and a CANTAB software key, with a task design modified from the version by Robbins and colleagues (1994). The screen was placed on a table in front of seated participants, using a tablet stand with varying angle and distance from their eyes, depending on the participant's eyesight and preference. Participants could touch the press pad button with the fingers of their choice.

Procedure

The experimenter verbally explained the task and instructed the participants to respond promptly to certain target words by pressing the bottom button of the CANTAB press pad but to ignore distractors. The task consisted of 20 blocks, starting with two unrecorded practice blocks. The experimenter checked in with participants after each practice block, as participants could ask questions. Prior to each block, written instructions on the screen indicated the valence of the following block's targets and distractors. Targets and distracters were defined based on emotional valence; each could either be positive (e.g. happiness), negative (e.g. illness), or neutral (i.e. carpet). Words in each category were similar in length and usage-frequency (Hofland and Johansson 1982). Blocks were

presented in the following order: (1) targets = positive words, distractors = negative words; (2) targets = positive words, distractors = neutral; (3) targets = neutral words, distractors = negative words; (4) targets = neutral words, distractors = positive words; (5) targets = negative words, distractors = positive words; (6) targets = negative words, distractors = neutral words. This order was repeated three times. Each block in randomized order, 20 words, 10 targets and 10 distractors, flashed on the center of the screen for 300 ms followed by a 900 ms intertrial interval during which participants could respond (or not). Thus, each block lasted 24 sec. Participants could start the next block when ready by pressing any button.

Processing and Analyses

The CANTAB tablet outputted responses to AGN in the form of (1) mean response latency on correct trials (i.e. pressed the button upon seeing a word from the target valence category) in milliseconds; (2) total number of commissions errors (i.e. response recorded for distractors); (3) total number of omissions errors (i.e. no response recorded for targets). CANTAB made a distinction between all trials, all positive target trials, all negative target trials, or all neutral target trials as well as whether trials were shift trials (i.e. targets of current and previous blocks are different) or non-shift trials (i.e. targets of current and previous blocks have difference valence).

Emotional attention bias was quantified by computing a differential response latency score (RT bias; see Equation 1) and a normalized one (Normed RT bias; see Equation 2) from the AGN output. In both equations, RT_{pos} and RT_{neg} stand for the mean response latencies, in millisecond, on correct trials to positive and negative targets during non-shift

trials only. Scores above zero indicated an attentional bias towards positive words while scores below zero indicated an attentional bias towards negative words.

$$RT\ bias = RTneg - RTpos$$

Equation 1

$$Normed\ RT\ bias\ = \frac{RTneg - RTpos}{RTpos + RTneg}$$

Equation 2

Before inspection of the data, it was decided that only non-shift trials would be included in these emotional attention bias scores because shift trials introduced confounds unrelated to attentional bias (Meule, 2017). Subtracting mean response latencies eliminates age-effects in reaction time, as older adults are on average slower to respond and make more errors than younger ones (Demeyer & de Raedt, 2013; Mather & Carstensen, 2003; Rosler et al., 2005; Tomaszczyk & Fernandes, 2014). Computing a bias score (with or without normalization) also resulted in a majority of null scores for both commissions and omissions as most participants had the same number of errors for both positive and negative target trials; commission and omission scores therefore lacked the variance needed for any regression analyses and were thus disregarded.

Out of the 134 participants who completed the AGN, 3 participants were excluded for claiming to not understand the task and not responding according to instructions and 31 participants were excluded because they did not complete the fMRI scan or because their fMRI was invalidated during data preprocessing. Thus only 100 participants remained in the final sample.

FMRI data

Collection

MRI scans were performed with a 3T scanner (MR750 GE Healthcare, Waukesha, WI) using an 8-channel head coil. Three sets of echo planar images were collected during the fMRI task (231 volumes with 3 mm slice thickness and 1 mm gap, TR = 2000 ms, TE = 20, flip angle = 60˚, field of view = 220 mm, 96x64 matrix dimensions with 40 interleaved sagittal slices, ASSET parallel imaging with an acceleration factor of 2). T1-weighted structural images were collected using 3-dimensional magnetization-prepared rapid gradient-echo sequence (MPRAGE; Mugler & Brookeman, 1990) for high spatial resolution (TR = 8.2, TE = 3.2, flip angle = 12˚, field of view = 256 mm, 256x256 matrix dimensions with 160 axial slices, inversion time = 450 ms) registration of functional data.

Functional MRI task

Participants were asked to pay attention to a screen (800x600 mm) placed behind their heads, which was made visible via the reflection of a mirror attached to the head-holding apparatus. During fMRI scanning, participants passively viewed a full screen picture from the International Affective Picture System (IAPS pictures; Lang, Bradley, & Cuthbert, 2008) for 4 seconds, followed by a 2-second inter-stimulus interval, a 0.5 second neutral face picture in black and white from several databases (XM2VTSDB multi-modal face database, Messer at al., 1999; NimStim database, Tottenham et al., 2009; Montreal Set of Facial Displays of Emotion, Beaupre, Cheung, & Hess, 2000), and a random inter-trial interval of 3.5 to 27.5 seconds (mean duration = 7.5 seconds). Participants were instructed to identify the gender of the neutral face by pressing one of two buttons with their index (i.e. male face) or middle (i.e. female face) finger of a MRI

scanner-compatible command box. This low-level task allowed to control for task engagement during each trial without interfering with neural activity related to the previous IAPS picture viewing period. The neutral faces included the same number of male and females of broad age and ethnicities and were cropped just above the hair and below the chin, as well as edited to remove any visible accessory or facial hair. A 1-second crosshair appeared before the start of each trial to prompt one's attention (see Figure 1).

The task comprised three blocks, with pause and participant check-in between blocks. Each block consisted of 30 trials (i.e. 30 IAPS pictures and 30 neutral faces), including 10 trials with negative IAPS pictures (i.e. dying child), 10 neutral pictures (i.e. dishes on a table), and 10 positive pictures (i.e. laughing newly-weds). The 90 IAPS pictures were presented in a semi-random order, as there could not be more than two consecutive trials with same picture-valences and participants viewed one of two possible valence orders. There were only 45 different neutral faces, and each face was presented following two randomly selected pictures from the same valence category.

Processing

FMRI data were processed using custom-made scripts using the programming languages Python (Python Core Team, 2015) and Bash (Free Software Foundation, 2007), and FEAT (FMRI Expert Analysis Tool) Version 6.00, part of FSL (FMRIB's Software Library, www.fmrib.ox.ac.uk/fsl). Data were preprocessed by removing the first 4 volumes (resulting in 227 remaining volumes), reorienting scans when necessary using FSLREORIENT2STD, identifying and correct motion outliers using McFLIRT (for absolute motion displacement relative to the middle volume) and

FSL_MOTION_OUTLIERS (for within-volume motion with a criterion of 0.5 mm and above; Siegel et al., 2014), and removing skill and non-brain matter using BET. Additionally, FEAT performed spatial smoothing using a Gaussian kernel at 5mm full-width at half-maximum, grand-mean intensity normalization, and high-pass temporal filtering. Additional processing steps included correction of time series autocorrelation, resampling of functional data to 2mm3 isotropic voxels, boundary-based linear registration (BBR) to each participants' structural scans, and nonlinear (12 degrees of freedom) normalization of functional data into Montreal Neurological Institute template space with a warping resolution of 10 mm.

Fifteen participants were excluded during pre-processing because 6 had excessive movement at > 0.5 mean framewise motion during all three runs, 5 had 20% or more absolute displacement at > 0.6 mm threshold during all three runs, 2 failed to provide behavioral responses on at least 25% of trials, and 2 had distorted functional data. Participants who did not complete the Affective Go/no-Go task were not included in fMRI analyses, because analyses served to explore the association between emotional attention bias and brain functionality differences. The resulting sample was of 100 participants (Milwaukee subsample: n = 28). Among those 100 participants, 85 had three valid runs, 9 had two valid runs, and 6 only had one valid run.

Modeling

The first-level general linear model (GLM) included 14 regressors, including 6 regressors of interest with two separate IAPS picture and neutral faces regressors for each picture valence (i.e. Negative, Positive, or Neutral), and 8 regressors of no interest with 6 motion parameters and their first- and second- order derivatives, a mean-centered

response time to face presentations, and a motion confound regressor for each volume with > 0.5 mm framewise displacement. Second-level models were fixed effect models averaging across task blocks. Initial models involved three contrasts based on the valence of the IAPS pictures, with Negative vs. Neutral, Negative vs. Positive, and Positive vs. Negative. Two additional contrasts were included at post-hoc to explore if possible effects were negative-valence driven (Negative vs. Positive and Neutral) or valence-unspecific emotion-content driven (Negative and Positive vs. Neutral).

Regions-Of-Interest (ROIs) analyses

To test hypotheses about specific brain regions (bilateral vmPFC, bilateral amygdala, and bilateral lateral PFC), BOLD signal intensity in each of three a priori chosen ROIs were calculated as mean parameter estimates for each contrast from voxels (at 2 mm spatial resolution) with ≥ 50% probability in each region, using the Harvard-Oxford Probabilistic Cortical and Subcortical Structural atlases (Desikan et al., 2006), FSLMATHS, and FSLMEANTS. For each region, a bilateral, a left, and a right mask were used to extract each estimate. The vmPFC was defined as mask number 25 of the cortical atlas, which encompasses the frontal medial cortex (BA 12, part of 32; see Figure 2). The amygdala was defined as mask number 10 of the subcortical atlas, including the whole amygdala, with no specificity of nuclei (see Figure 3). The lateral PFC was defined as mask number 6, which encompasses the inferior frontal gyrus (partial BA 45/47; see Figure 4). Additionally, the left and right vmPFC (BA 32/10; see Figure 5) and vlPFC (BA 44/45 see Figure 6) ROIs found in a study by van Reekum and colleagues (2018) were replicated.

FSLMATHS deleted voxels which did not contain brain matter in all participants, for each ROI. Multiple linear regression analyses served to explore individual differences in ROIs, using either age or computed AGN scores, and global mean BOLD signal estimates (calculated with FSLMEANTS) as independent variables, and ROI brain BOLD signal estimates of each contrast as dependent variables. The global mean estimate was included to account for age-related decline in cortical BOLD signal intensity (Fjell & Walhovd, 2010) and for state-induced general brain activations (e.g. difference in overall brain activity when being aroused or sleepy). All results involving the two additional contrasts (Negative vs. Neutral and Positive; Negative and Positive vs. Neutral) were corrected for multiple comparisons testing using a Bonferroni-corrected p value of 0.025 (1 ROI mask * 2 contrasts) for analyses involving the initial contrasts (i.e. Negative vs. Neutral, Negative vs. Positive, and Positive vs. Neutral); otherwise, the significance threshold was determined by a p value of 0.05.

Whole-brain analyses

Whole-brain voxelwise analyses were conducted with all contrasts to identify regions activated during the viewing of IAPS pictures belonging to specific valence categories. Cluster threshold correction was set at a Z threshold of 3.1 and a cluster-corrected significance value of $p < 0.05$. The first GLM was a group-level analysis which only included a mean regressor, that is, the model averaged every participant's block scans together. To explore the interaction between individual differences of age and emotional attention biases on brain responses during IAPS picture viewing, an age regressor, an RT bias regressor, and a Normed RT bias regressor were each added to three later and separate GLM analyses. Two additional GLM analyses included the mean-across-

participants-regressor, age, and one of the AGN regressors, where age was only present as a control variable.

Results

Emotional attention bias did not differ between age groups

Two emotional attention bias scores were computed from raw Affective Go/no-Go data of response latencies on non-shift positive and negative target trials, where positive values indicated a positive attention bias. Participants showed an overall attention bias towards positive stimuli but there was no significant difference in the RT bias scores between younger (M = 26.04, SD = 58.29) and older (M = 12.66, SD = 41.32) adults ($t(98) = 1.315$, $p = .192$.; see Figure 7). Similarly, normed RT bias scores were not significantly different between younger (M = .023, SD = .067) and older (M = .012, SD = .039) adults ($t(98) = 1.007$, $p = .317$; see Figure 8). There were no linear relationship between age and RT bias scores (R^2 = -.01, $F(1,99) = .022$, β = -.015, $p = .883$) nor normed RT bias scores (R^2 = -.009, $F(1,99) = .096$, β = .031, $p = .758$). When removing one outlier participant whose RT bias (*score* = -239.92) and normed RT bias (*score* = -.338) scores were more than three standard deviation away from their respective mean, the linear relationship between age and RT bias scores (R^2 = .008, $F(1,98) = 1.751$, β = -.133, $p = .189$; see Figure 9) or normed RT bias scores (R^2 = .005, $F(1,98) = 1.527$, β = -.124, $p = .22$; see Figure 10) remained non-significant. Despite these results, individual analyses were pursued in the imaging data of those participants to identify the brain regions associated with differences in emotional attention bias scores.

Global mean BOLD signal was not associated with Age

To control for age-related differences in brain tissue and subsequent brain signal, the global mean BOLD signal for each IAPS picture period was calculated. Several simple linear regressions however did not find significant associations between age and global mean BOLD signal for any of the contrasts (i.e. Negative vs. Neutral, Negative vs. Positive, Positive vs. Neutral, Negative vs. Neutral/Positive, Neutral vs. Negative/Positive IAPS picture period).

Findings from van Reekum and colleagues (2018) were partially replicated

To replicate findings by van Reekum and colleagues (2018), simple linear regressions tested the association between age and mean BOLD signal in two specific spherical ROIs, the bilateral vmPFC and vlPFC. Age was not associated with mean BOLD signal differences between negative and neutral IAPS picture periods for the right vmPFC nor right vlPFC. Age was significantly negatively associated with left vmPFC mean BOLD signal difference for the Negative vs. Neutral IAPS picture contrast (R^2 = .054, F(1,99) = 6.652, p = .011; see Figure 11, Table 1) and marginally negatively associated with left vmPFC mean BOLD signal difference for Negative vs. Neutral/Positive IAPS picture contrast (R^2 = .04, F(1,99) = 5.127, p = .026; see Table 1). This finding contradicted the findings by van Reekum and colleagues (2018) which reported the inverse association between age and left vmPFC BOLD signal differences. Congruently with van Reekum and colleagues' (2018) findings however, there was a trending negative association between age and left vlPFC mean BOLD signal difference for the Negative vs. Neutral IAPS picture contrast (R^2 = .027, F(1,99) = 3.795, p = .054; see Figure 12, Table 1).

Age affected emotional processing in PFC regions and the Amygdala

Next, simple linear regressions tested whether age significantly predicted variance of mean BOLD signal differences within selected ROIs, namely the vmPFC, the amygdala, and the lateral PFC, for all contrasts. In the left vmPFC, age was significantly negatively associated with mean BOLD signal differences between negative and neutral IAPS picture periods (R^2 = .058, F(1,99) = 7.127, p = .009; see Table 2), positive and neutral IAPS picture periods (R^2 = .058, F(1,99) = 7.087, p = .009; see Table 2), and negative and positive versus neutral picture periods (R^2 = .087, F(1,99) = 10.457, p = .002; see Figure 13, Table 2). In the left amygdala, age was significantly negatively associated with mean BOLD signal differences between positive and neutral IAPS picture periods (R^2 = .052, F(1,99) = 6.414, p = .013; see Figure 14, Table 3). Age was marginally negatively associated with mean BOLD signal differences in the right amygdala between negative and neutral IAPS picture periods (R^2 = .026, F(1,99) = 3.612, p = .06; see Table 3) but significantly negatively associated with mean BOLD signal differences between negative, and neutral and positive IAPS picture periods (R^2 = .041, F(1,99) = 5.27, p = .024; see Figure 15, Table 3). Finally, age was marginally negatively associated with mean BOLD signal difference in the left lateral PFC between negative and neutral IAPS picture periods (R^2 = .028, F(1,99) = 3.836, p = .053; see Table 4) and between negative, and neutral and positive IAPS picture periods (R^2 = .038, F(1,99) = 4.924, p = .029; see Figure 16, Table 4), and significantly negatively associated with mean BOLD signal difference in the left lateral PFC between negative and positive IAPS picture periods (R^2 = .03, F(1,99) = 4.058, p = .047; see Table 4).

There were no significant association between age and right lateral PFC nor right vmPFC BOLD signal differences for any given contrast.

Attention Positive Bias affected emotional processing in the left lateral PFC

Several simple linear regressions tested whether emotional attention bias scores were associated with mean activity intensity in the three previously stated ROIs, in all contrasts. Results showed that neither emotional attention bias scores were associated with mean BOLD signal in the left nor right Amygdala, in the left nor right vmPFC, nor in the right lateral PFC for any given contrast. However, RT bias scores were marginally negatively associated with left lateral PFC mean BOLD signal differences between negative, and neutral and positive IAPS picture periods (R^2 = .04, F(1,99) = 5.117, p = .026; see Figure 17, Table 5). Similarly normed RT bias scores were significantly negatively associated with left lateral PFC BOLD signal differences between negative, and neutral and positive IAPS picture periods (R^2 = .041, F(1,99) = 5.24, p = .024; see Figure 18, Table 5).

Brain activity varies with image valence but not age nor emotional attention bias

The GLM with one regressor which averaged every participant's blocks together was the only model which yielded significant clusters of activations for all contrasts during whole-brain voxelwise analyses using the Z threshold of 3.1 (see Table 6).

Within the emotion regulatory network (Kohn et al., 2014), passively viewing negative pictures, compared to neutral and/or positive ones, induced activity in the right lateral middle frontal gyrus, the left lateral orbital frontal cortex (OFC), the left medial superior frontal gyrus, bilateral lateral inferior frontal gyrus, and both amygdala. Positive pictures, compared to neutral or positive ones, induced activity in the left lateral frontal

pole and bilateral medial frontal cortex. Emotional, positive and/or negative pictures, compared to neutral ones, also activated regions of the bilateral occipital lobe, the left precentral gyrus, and several regions of the bilateral occipito-parietal, parietal, temporal cortices.

All other models, involving an (1) age regressor, (2) RT bias regressor, (3) normed RT bias regressor, or a (4) RT bias regressor controlling for age and a (5) normed RT bias regressor controlling for age yielded no brain clusters, indicating that no sizable brain region was more activated (nor less activated) with increasing age and/or bias towards positive stimuli.

Discussion

This study investigated the interaction between age and emotional attention bias, and their association with brain activity during emotional stimuli processing within the emotion regulatory network. This work aimed at contributing towards the ongoing debate on emotional aging, where either age-related neurobiological decline (Cacioppo et al., 2011) or age-induced mood-enhancement goals (Carstensen & Mikels, 2005), at least sometimes (Murphy & Isaacowitz, 2008), result in an age-related "positivity effect" in attention (Carstensen & Mikels, 2005).

A first hypothesis was that age would be positively associated with an emotional attention bias towards positive stimuli as older adults, but not younger ones, would exhibit such bias. However, no difference between younger (26-47 year-old) and older (48-76 year-old) adults in emotional attention biases were found, as seen by the difference and the normed difference in response latencies between negative and positive target correct trials during the affective Go/no-Go task. Linear association between age

and bias scores was assessed to bypass any grouping effect, as individuals close in age may be placed in different age groups. However, no significant linear relationships were found between age and neither of the computed emotional attention bias scores. The affective Go/no-Go task is a fast-paced task where participants are instructed to focus on accuracy, and consequently do not have time to implement mood-enhancing strategies or consciously show preferences for certain responses (e.g. preferential response to positive compared to negative target words). This result suggests that without goal implementation, emotional information is perceived and processed similarly throughout adulthood, which seems to contradict the neurobiological decline argument in favor of the "positivity effect".

More research is however needed before affirming that there is no age-related involuntary emotional attention bias. Indeed, there are several reasons contributing to the fact that studies on the Affective Go/no-Go task or the "positivity effect" usually report small effect sizes, or no age-related differences at all (Elliot et al., 2002; Lenehan et al., 2015; Murphy et al., 2016; Schultz et al., 2007; Williams, Watts, & Macleod, 1997). Firstly, individual differences in Affective Go/no-Go task performance is influenced by factors other than age, such as socioeconomic status (Noble, McCandliss, & Farah, 2007) or psychiatric history (Elliot et al., 2004; Erikson et al., 2005; Righi, Mecacci, & Viggiano, 2009). Future research should therefore control for demographic information (i.e. gender, location, education level, etc…) history of affective disorders when analyzing Affective Go/no-Go task data.

Secondly, Meule (2017) found that shift trial scores of the Affective Go/no-Go task (i.e. target valence category differs from the previous block's) contained confound

information unrelated to emotional attention bias, such as motor and attentional impulsivity, which led to the decision to only use non-shift trials when computing RT bias and normed RT bias scores. However, it is possible that these confounds contribute to one's emotional attention biases, as involuntary biases may be a function of one's attentional impulsivity. There is some evidence across the literature that emotional attentional biases are larger during early (i.e. unprompted, unrehearsed) compared to later attentional processes (for a review: Pool, Brosch, Delplanque, & Sander, 2016). Future research should therefore look at all trials, non-shift and shift trials, as well as shift trials separately, when computing emotional attention bias scores from raw Affective Go/no-Go task data.

Lastly, some studies suggest that the "positivity effect" is actually an age-related bias towards neutral information. Indeed, older adults seem to find neutral compared to emotional (positive or negative) information more rewarding (van Reekum et al., 2011) and therefore pay more attention to neutral rather emotional information (Demeyer & de Raedt, 2013; Mather & Carstensen, 2003; Rosler et al., 2005; Tomaszczyk & Fernandes, 2014; van Reekum, et al., 2011) while younger adults prefer to attend emotional rather than neutral stimuli. Future research should therefore compute a bias-towards-neutral-stimuli score (e.g. using RT differences between positive or negative, and neutral target trials during the Affective Go/no-Go task) and investigate the result's association with age.

Global mean BOLD signal was calculated to account for age-induced changes in brain tissue properties and subsequent BOLD signal intensities (D'Esposito, Deouell, &

Gazzaley, 2003) but was not found to be associated with age. Therefore, our analyses were carried out without any metric that accounted for age-related brain differences.

When replicating findings by van Reekum and colleagues (2018), we found trending results that corroborated the finding of a negative association between left (but, similarly to the study, not right) vlPFC BOLD signal difference between negative and neutral IAPS picture presentation and age. Older adults therefore recruit the ventrolateral prefrontal cortex less than younger adults when viewing aversive stimuli, an area activated during stimuli reappraisal and conscious attentional control (Morawetz et al., 2016; Nitschke et al., 2005; Oschner et al., 2002; Urry et al., 2006). This finding was corroborated in this study as left, but not right, lateral PFC (i.e. using an additional mask) BOLD signal difference between negative and neutral, and between negative, and neutral/positive IAPS picture presentation were also found to be negatively associated with age. Similarly to the vlPFC, the left lateral PFC is associated with stimuli reappraisal and conscious attentional control during emotion regulation paradigms (Martins, Ponzio, Velasco, Kaplan, & Mather, 2015; McRae, Hughes, Chopra, & Gabrieli, 2010; Nitschke et al., 2005; Oschner et al., 2002). Together, results suggest that older adults rely less on cognitive control-related active processes when coping with difficult stimuli. Future research should investigate whether such age-related difference is due to the fact that as one becomes older, one becomes less likely to seek emotional regulatory strategies such as reappraisal when confronted with unpleasant information, or whether other brain regions take over such function overtime.

Left vmPFC BOLD signal difference between negative and neutral IAPS picture presentation was also found to be negatively associated with age while van Reekum and

colleagues (2018) found a positive association between these two variables. The validity of the current finding was however corroborated when left vmPFC BOLD signal difference between negative or positive and neutral IAPS picture presentation, using a different mask, was found to also be significantly negatively associated with age. It is therefore uncertain whether older adults recruit the left vmPFC less than younger adults do when viewing aversive stimuli. Future research should aim to clarify this uncertainty, and find which finding is a false positive, if not both. Despite the current use of two different masks when looking at activity in the vmPFC, these contradictory results may be explained by several differences between both studies.

The current study recruited a younger age group (i.e. mean age of sample was 10 years younger), while van Reekum and colleagues (2018) pointed out that the age-related difference in vmPFC functionality was observed in the oldest participants. It is therefore possible that the scope of our study was not sufficient to detect the effect. We also used a different Z-threshold when considering which voxels were considered active in any given contrast, despite keeping every single preprocessing step and decisions consistent with the ones reported by van Reekum and colleagues (2018). FMRI preprocessing pipelines and standards are laboratory-dependent and not always consistent across the field. Given the current practice in this study's laboratory, the Z-threshold was slightly more conservative (p = 3.1 instead of 3.24) than the one used by van Reekum and colleagues (2018). Thus, future research should consider keeping every preprocessing and analysis step consistent with the study it is attempting to replicate.

Finally, our study is currently lacking a reliable method of controlling for age-induced differences in BOLD signal and underlying brain tissue properties. Van Reekum

and colleagues (2018) took this factor into consideration by calculating and including the Grey Matter Probability (GMP) in voxels during their analyses, particularly when looking at the lateral PFC, an area particularly prone to age-related atrophy (Fjell & Walhovd, 2010). The GMP allows to control for localized age-related differences in BOLD signal instead of relying on global signal. Despite evidence of preserved vmPFC structure across the lifespan (Fjell & Walhovd, 2010), future research should consider controlling for GMP when analyzing the association between age and mean vmPFC BOLD signal for a more exhaustive analysis.

Including the GMP variable in future analyses is also suggested when considering the results of the current whole-brain analyses. When controlling for age or using age was a predictor of neural activity, the analyses yielded that no brain area was more or less activated during any of the five contrasts calculated. One possible conclusion is that there are no robust age-related differences in brain functionality during passive emotional picture viewing. Voxels, especially located in the outward-most cortical area, may however be represented by a lower intensity value in older participants due to age-related cortical atrophy (Fjell & Walhovd, 2010) and may thus lack brain matter in older participants. It is therefore also possible that accounting for such age-related differences in one's brain structure and voxel-dependent BOLD signal, by controlling for GMP, will yield different results.

The bilateral amygdala was found to respond differently to emotional stimuli depending on age. Although van Reekum et colleagues (2018) did not find an age-related difference in amygdala response to emotional stimuli, this current finding corroborates several studies which found age to be negatively associated with amygdala reactivity to

aversity stimuli (Mather, 2016; Samanez-Larkin & Carstensen, 2011). An unpredicted and unprecedented asymmetry between left and right amygdala response to negative or positive compared to neutral IAPS pictures was found. Amygdala response to aversive stimuli is lessened by medial PFC down-regulation (Etkin, Egner, & Kalisch, 2011; Hartley & Phelps, 2010; Kim, Somerville, Johnstone, Alexander, & Whalen, 2003; Oschner & Gross, 2004; Urry et al., 2006). Thus, the current findings that less left vmPFC responsivity to negative stimuli compared to neutral with increasing age may have predicted a bigger left amygdala response to negative compared to neutral stimuli with increasing age. Instead, the present findings show that the older the participant, the lesser the left amygdala response to positive compared to neutral stimuli. There are at least two possible and not mutually-exclusive interpretations for these results, which future research should explore.

Firstly, it is possible that older adults were less excitable or moved by emotional pictures compared to younger adults, which translated into lesser amygdala response to such stimuli, but also lesser use of executive functioning in the vmPFC and even lateral PFC to regulate one's emotional response to negative stimuli. The MIDUS study offers an opportunity to test this interpretation. In the MIDUS study, after the fMRI scan, participants completed arousal ratings of emotional and neutral IAPS pictures that they saw previously during the scanning session. This interpretation would be supported if, in part, lower arousal ratings were associated with both older age and lesser vmPFC, lateral PFC, and amygdala response to negative compared to neutral IAPS pictures. Such results would simplistically indicate that as adults get older, they neurologically react less to

aversive events, and thus require less emotion regulatory processes, while experiencing low emotional arousal.

Secondly, greater functional connectivity between the vmPFC and the amygdala, not just the amount of relative activity in each area, has been widely associated with lesser reaction to and more positive affect following aversive stimuli (Jackson et al, 2003; Jacques et al., 2010; Mather, 2016; Ochsner et al., 2004; Sakaki & Mather, 2013; Tomasi & Volkow, 2012). Although currently untested, it is possible that a weakened functional connectivity between the two areas enabled each to respond less to aversive stimuli, independently from one another. As far as we know, age has not yet been found to influence the strength of vmPFC-amygdala functional connectivity (Mather, 2016). Thus, future research should explore the individual differences in the relationships between emotional reactivity and regulation, vmPFC-amygdala functional connectivity, and age.

BOLD signal difference between negative, and neutral/positive IAPS picture presentation in the left lateral PFC, but not the amygdala, nor the vmPFC, has been found to be (negatively) associated with emotional attention bias scores. Given the functions attributed to the lateral PFC mentioned earlier, this result indicates that emotional attention biases are dependent on the same area recruited during conscious control and reappraisal of negative stimuli, as less attempt to control one's reaction to aversive stimuli seems to result in an attention bias towards positive stimuli. In this present study, it is not known whether participants engaged in reappraisal or any attention control efforts during the fMRI task. A possible interpretation however, to be tested, is that individuals who are involuntarily more likely to pay attention to positive and rewarding information and likewise less likely to spontaneously attend to unpleasant information,

are the same individuals who will less actively put efforts in diverting their attention away from aversive stimuli. This interpretation is in line with a study conducted by Elliot and colleagues (2002) who found that emotionally healthy controls recruit the lateral PFC less than depressed patients do when paying attention to negative stimuli. Future research may study this association in the context of one's affective style and investigate whether such individuals are more likely to experience positive emotions in their daily life, and whether their tendency to disengage with negative stimuli is motivated by mood-enhancing goals or is the result of a lesser cognitive ability to process negative information.

In conclusion, this study is contributing several insights into the current debates on the topic of emotional aging and cognition. The MIDUS Refresher sample size and experimental paradigm, enabled a replication of a study by van Reekum and colleagues, as well as a thorough analysis of the relationship between age, involuntary emotional attention biases, and age-related functional changes in the emotion regulatory network. Aging is associated with decrease vmPFC, lateral PFC, and amygdala activation during negative information processing, but is unassociated with attention biases. Current findings leave room for several interpretations because this study corroborated only some results from previous studies. Indeed, there is uncertainty as to whether older age brings along changes in one's ability to process emotional stimuli and thus one's likelihood of experiencing certain emotions, as well as to whether one's use of cognitive control over one's attention to emotional stimuli rely on different neural mechanisms with increasing age. Future research should pay attention to methodological differences between studies on the topic when interpreting results and incorporate additional control variables in their

approach. Such control variables would include a measure of prompted emotion regulation strategies (e.g. explicit reappraisal) when studying the relationship between age and lateral PFC activation during aversive events, as well as an index of gray matter probability in fMRI analyses of heterogeneous age groups.

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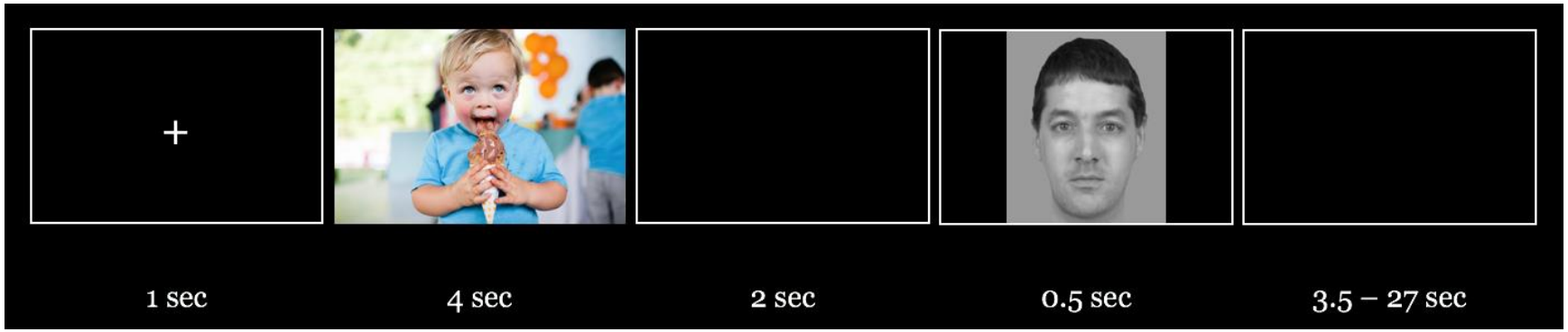

Figure 1. Schematic of an fMRI task trial. Each trial, participants viewed for four seconds a colored picture from the International Affective Picture System (Lang, Bradley, & Cuthbert, 2008) corresponding to either a positive (depicted here), negative, or neutral valence category. After a two second inter-stimuli interval, a black-and-white neutral face was presented for 0.5 second, and participants pressed a button to indicate the gender of the face depicted.

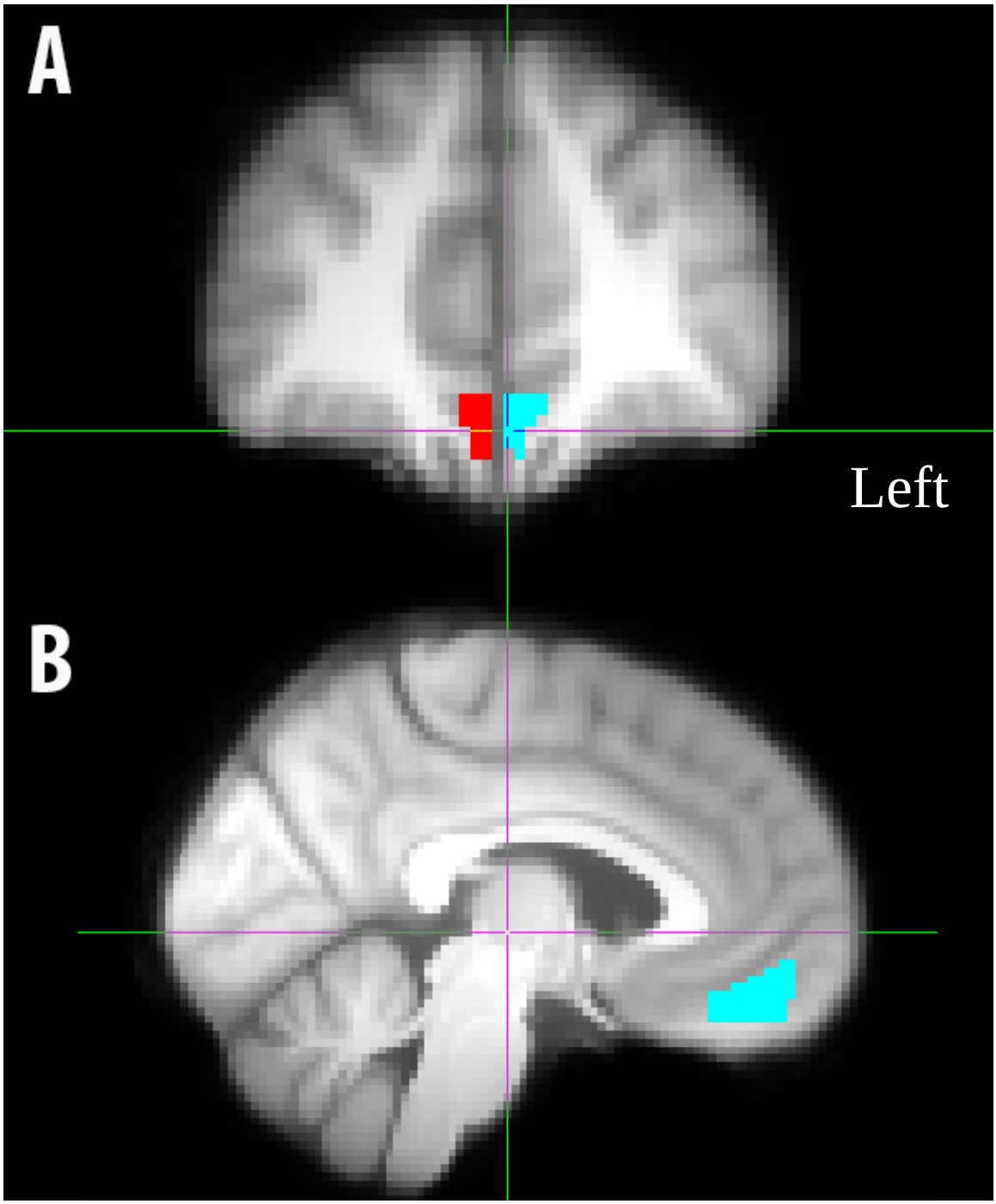

Figure 2. Coronal (A) and Sagittal (B) view of the ventromedial prefrontal cortex (vmPFC) using bilateral masks (right hemisphere in RED and left hemisphere in BLUE) of area 25 from the Harvard-Oxford Probabilistic Cortical atlas (2 mm spatial resolution).

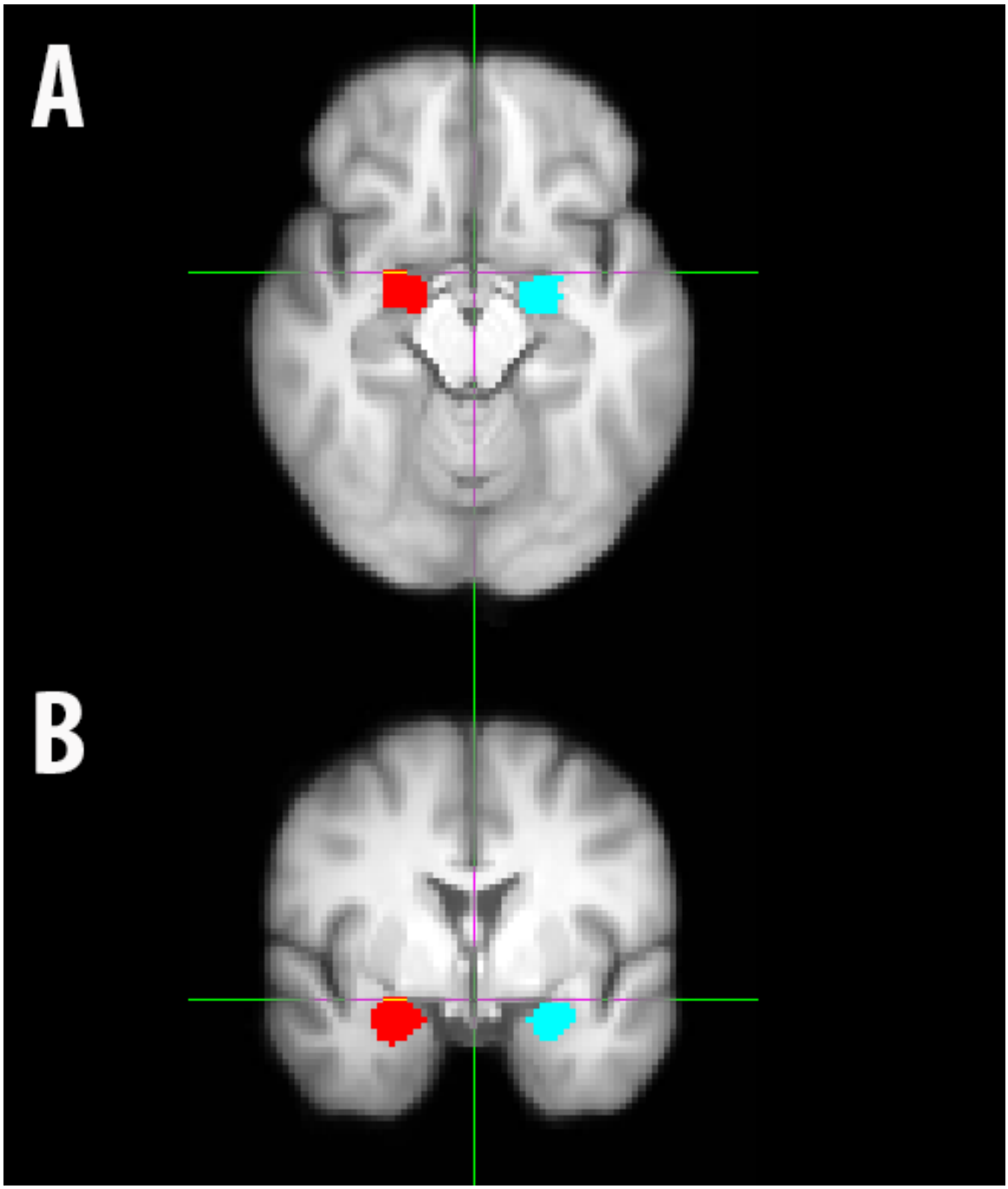

Figure 3. Horizontal (A) and Coronal (B) view of the Amygdala (all nuclei included) using bilateral masks (right hemisphere in RED and left hemisphere in BLUE) of area 10 from the Harvard-Oxford Probabilistic Subcortical atlas (2 mm spatial resolution).

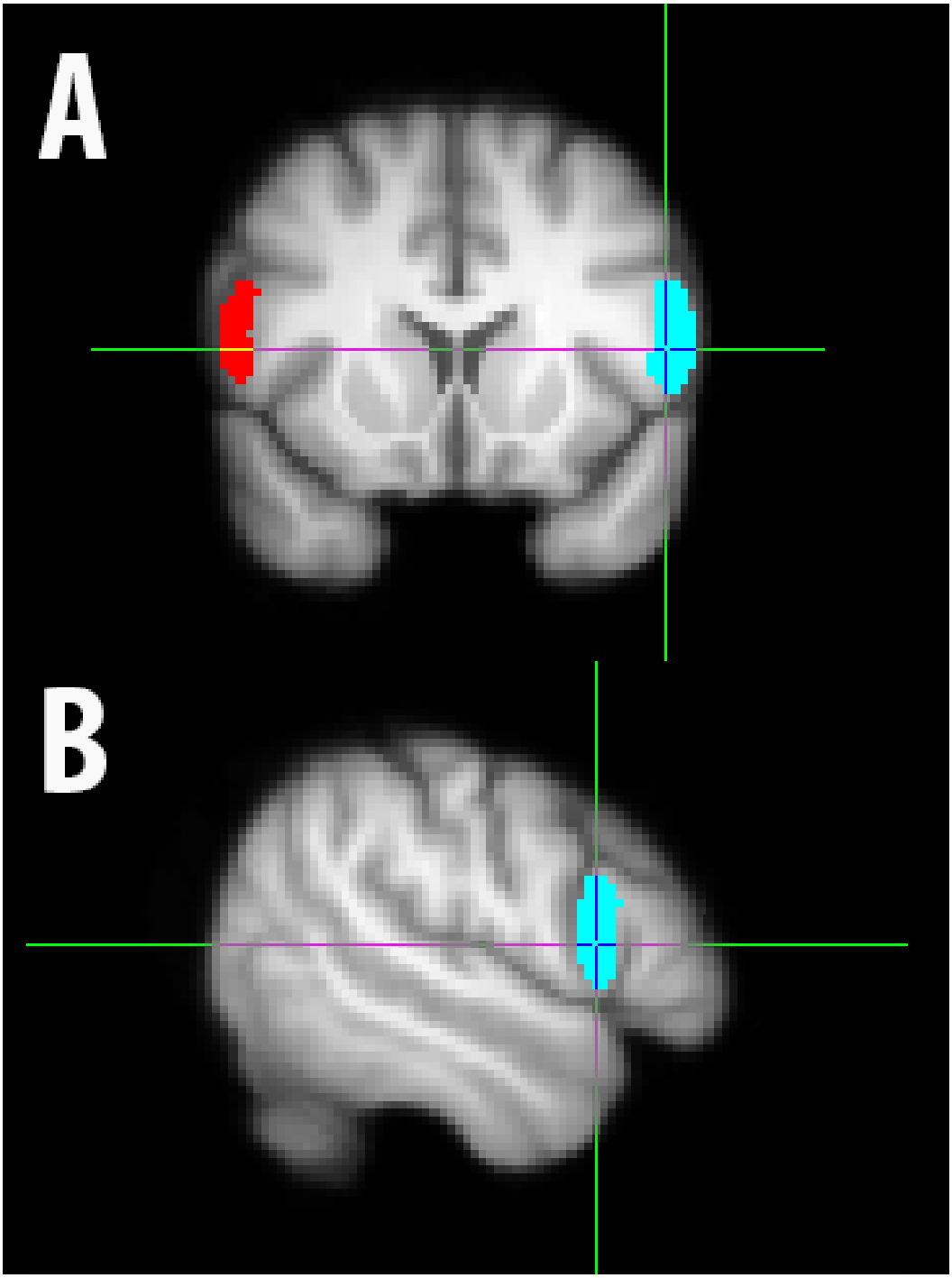

Figure 4. Coronal (A) and Sagittal (B) view of the lateral prefrontal cortex (lateral PFC) using bilateral masks (right hemisphere in RED and left hemisphere in BLUE) of area 6 from the Harvard-Oxford Probabilistic Cortical atlas (2 mm spatial resolution).

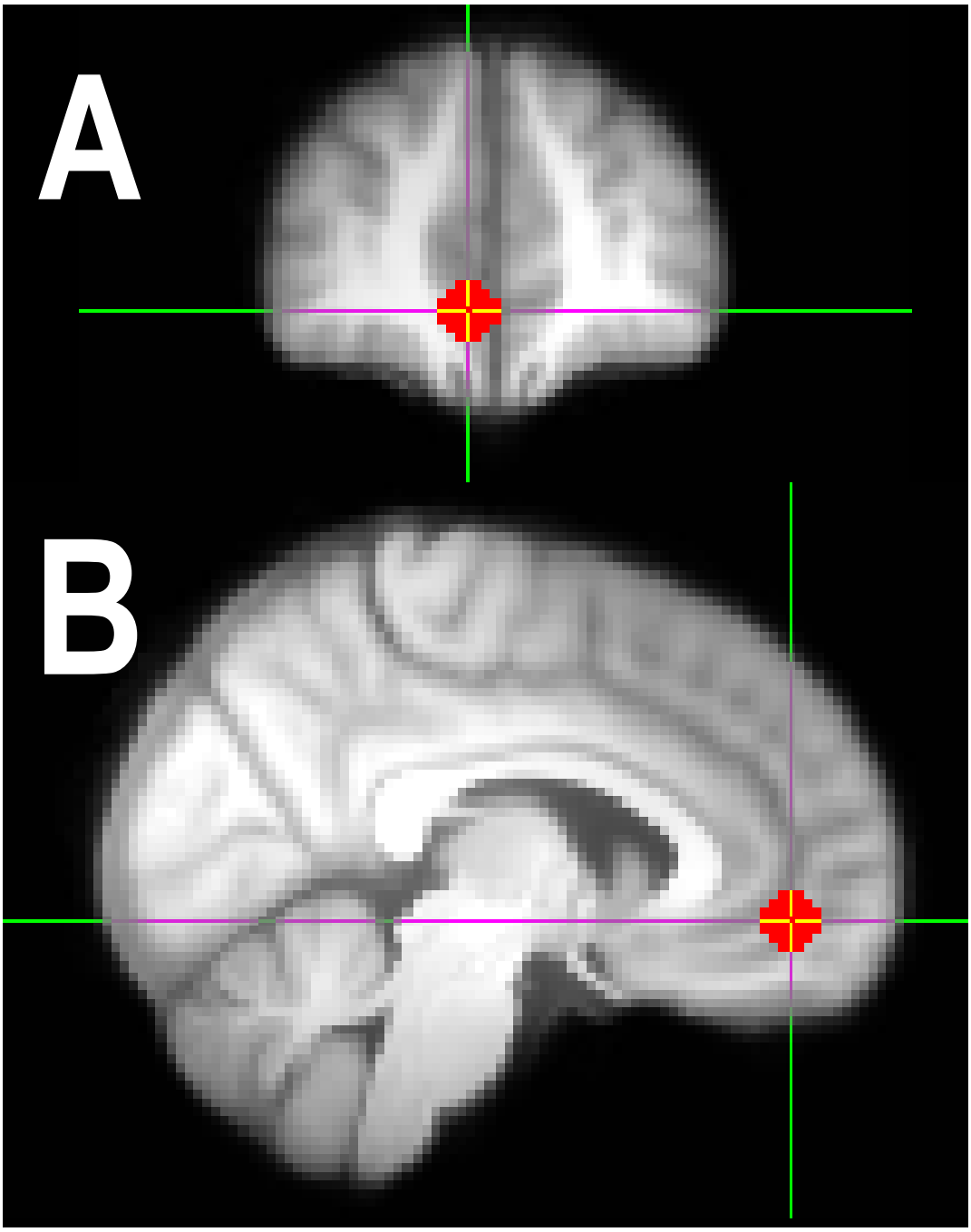

Figure 5. Coronal (A) and Sagittal (B) view of the right ventromedial prefrontal cortex (vmPFC) as defined by van Reekum and colleagues (2018). This ROI mask is replicated from reported coordinates in MNI space (volume = 1184 mm^3, X = 6 as depicted here or X = -6 for left hemisphere ROI, Y = 48, Z = -8).

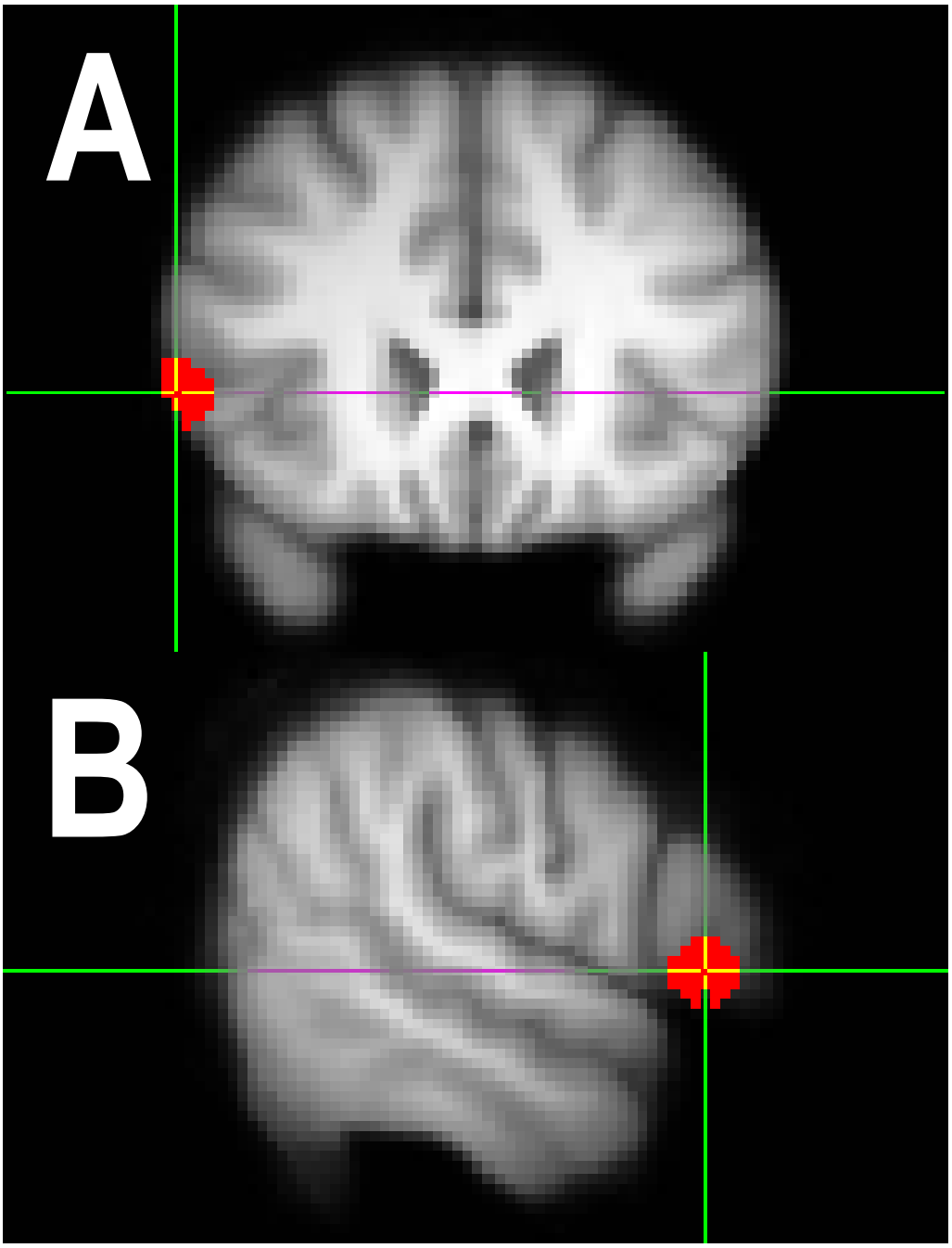

Figure 6. Coronal (A) and Sagittal (B) view of the right ventrolateral prefrontal cortex (vlPFC) as defined by van Reekum and colleagues (2018). This ROI mask is replicated from reported coordinates in MNI space (volume = 1256 mm^3, X = 58 as depicted here or X = -58 for left hemisphere ROI, Y = 24, Z = 2).

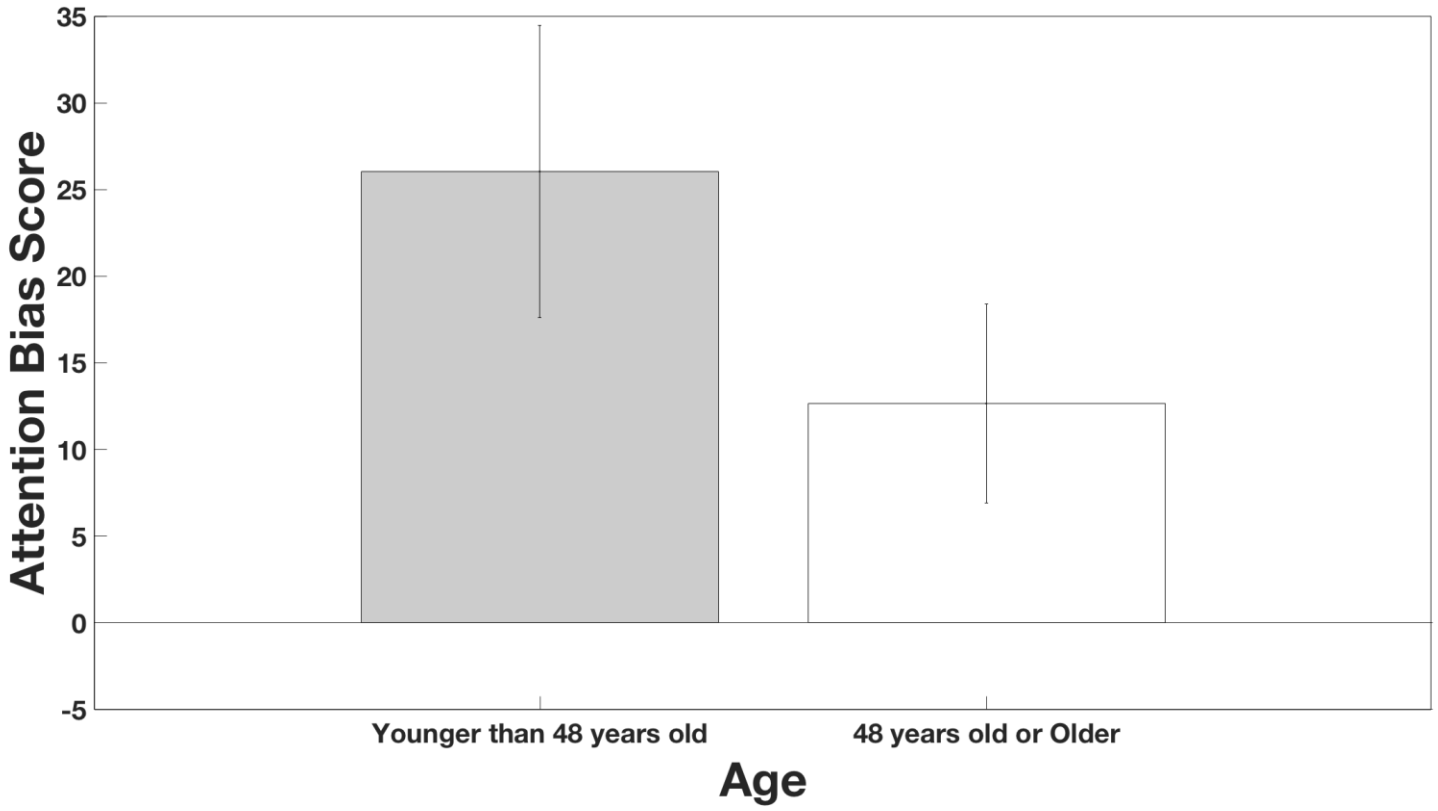

Figure 7. Mean emotional attentional bias in response latencies during correct trials are not different between younger (*n* = 48) and older (*n* = 52) participants. Error bars indicate the standard error to the mean.

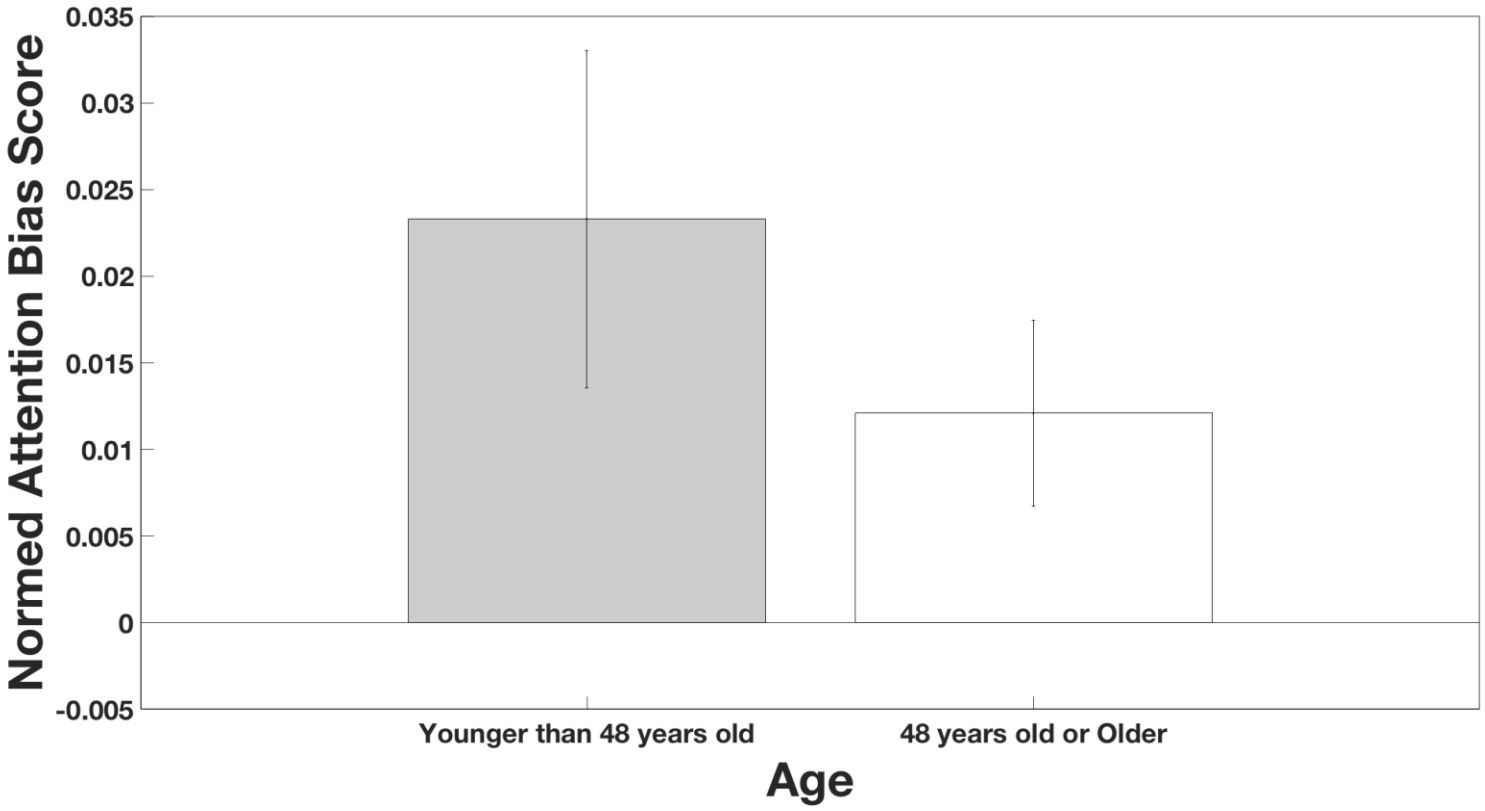

Figure 8. Normed mean emotional attentional bias in response latencies during correct trials are not different younger (*n* = 48) and older (*n* = 52) participants. Error bars indicate the standard error to the mean.

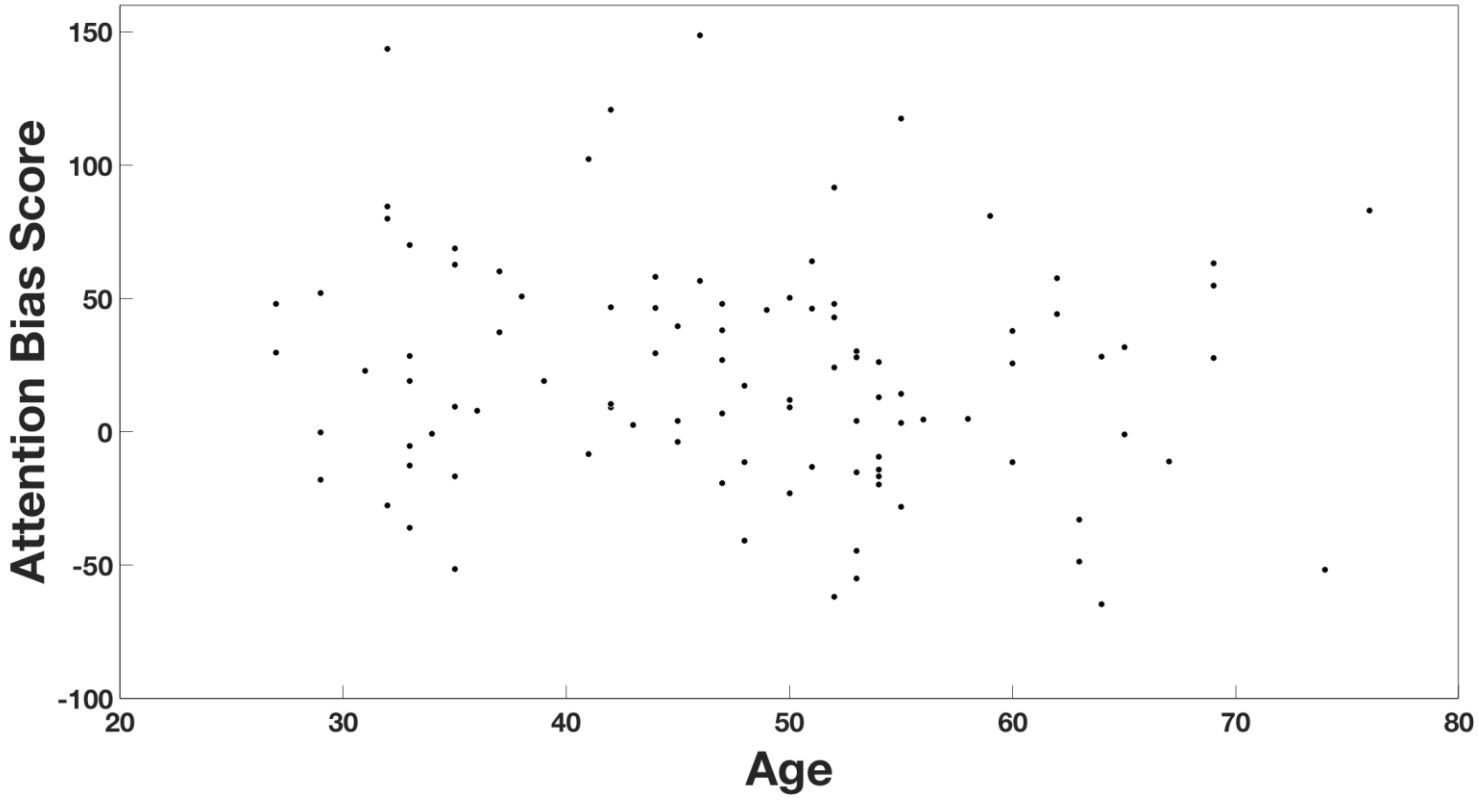

Figure 9. Scatterplot depicting the relationship between age and attention bias scores. Mean emotional attentional bias in response latencies during correct trials are not significantly associated with age.

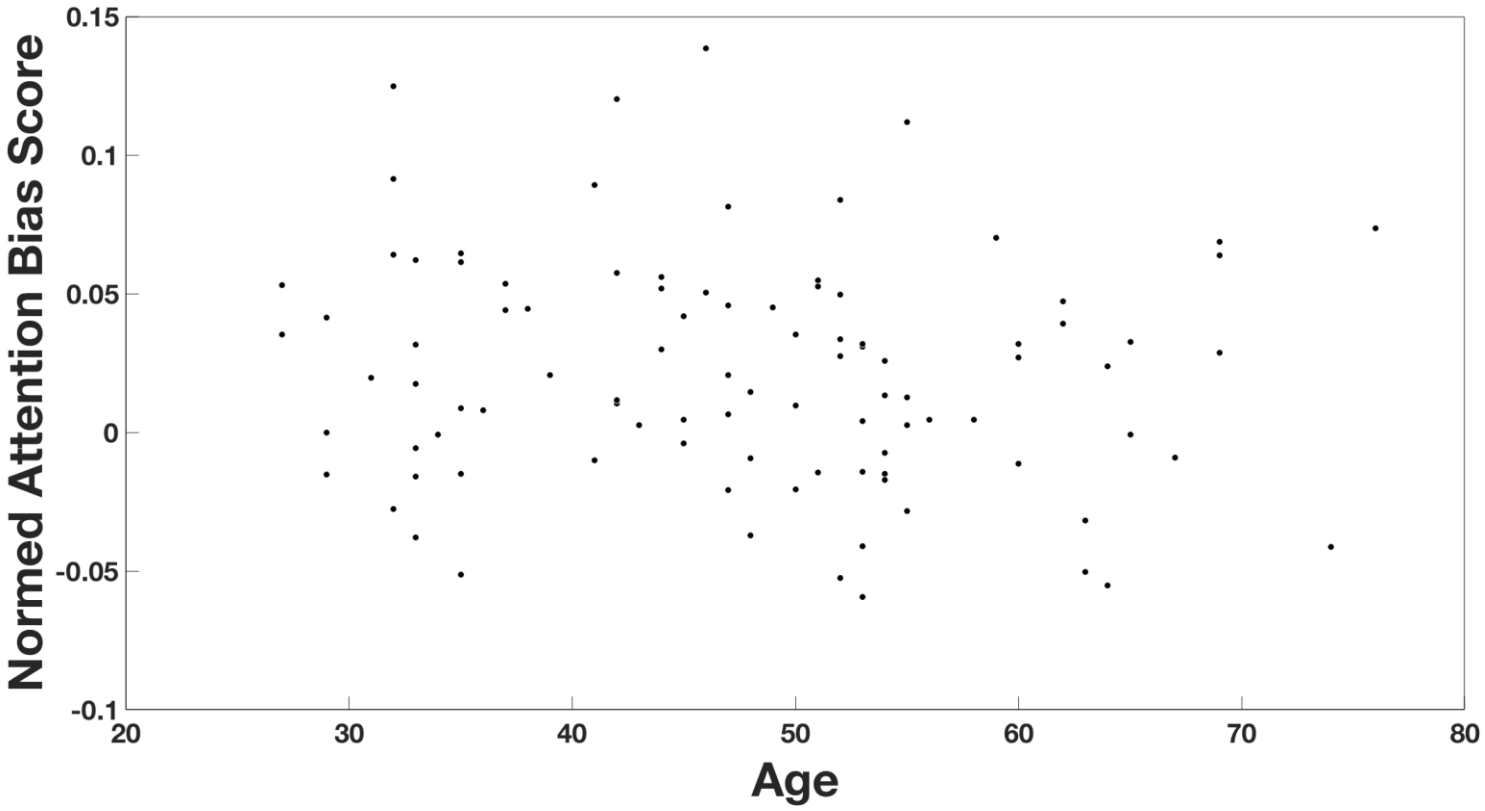

Figure 10. Scatterplot depicting the relationship between age and normed attention bias scores. Normed mean emotional attentional bias in response latencies during correct trials are not significantly associated with age.

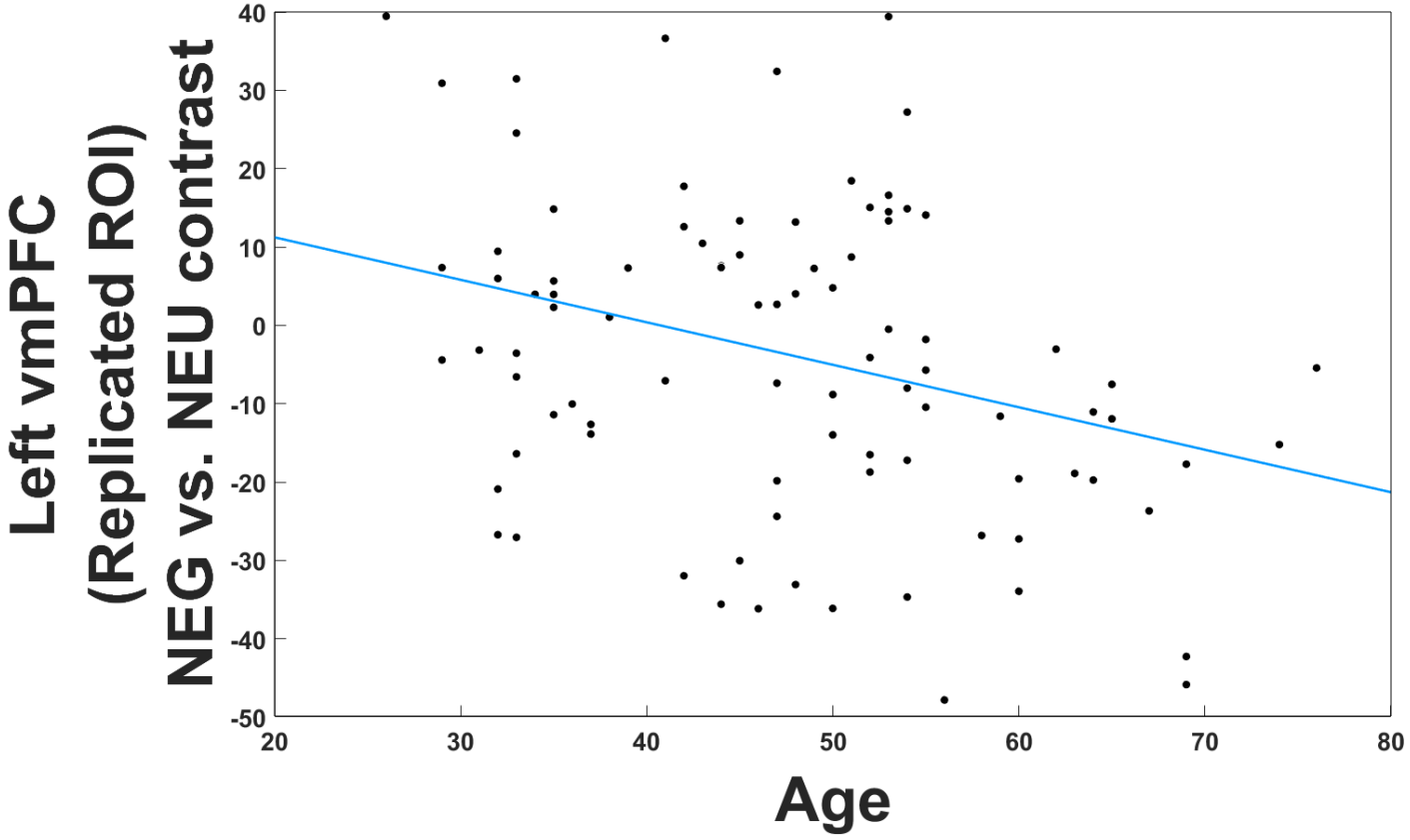

Figure 11. Scatterplot depicting the relationship between age and the BOLD signal difference between negative and neutral IAPS picture periods in the vmPFC as defined by van Reekum and colleagues (2018). Age was significantly negatively associated with left vmPFC BOLD signal during negative (NEG) vs. neutral (NEU) IAPS picture periods. The regression line is included in blue.

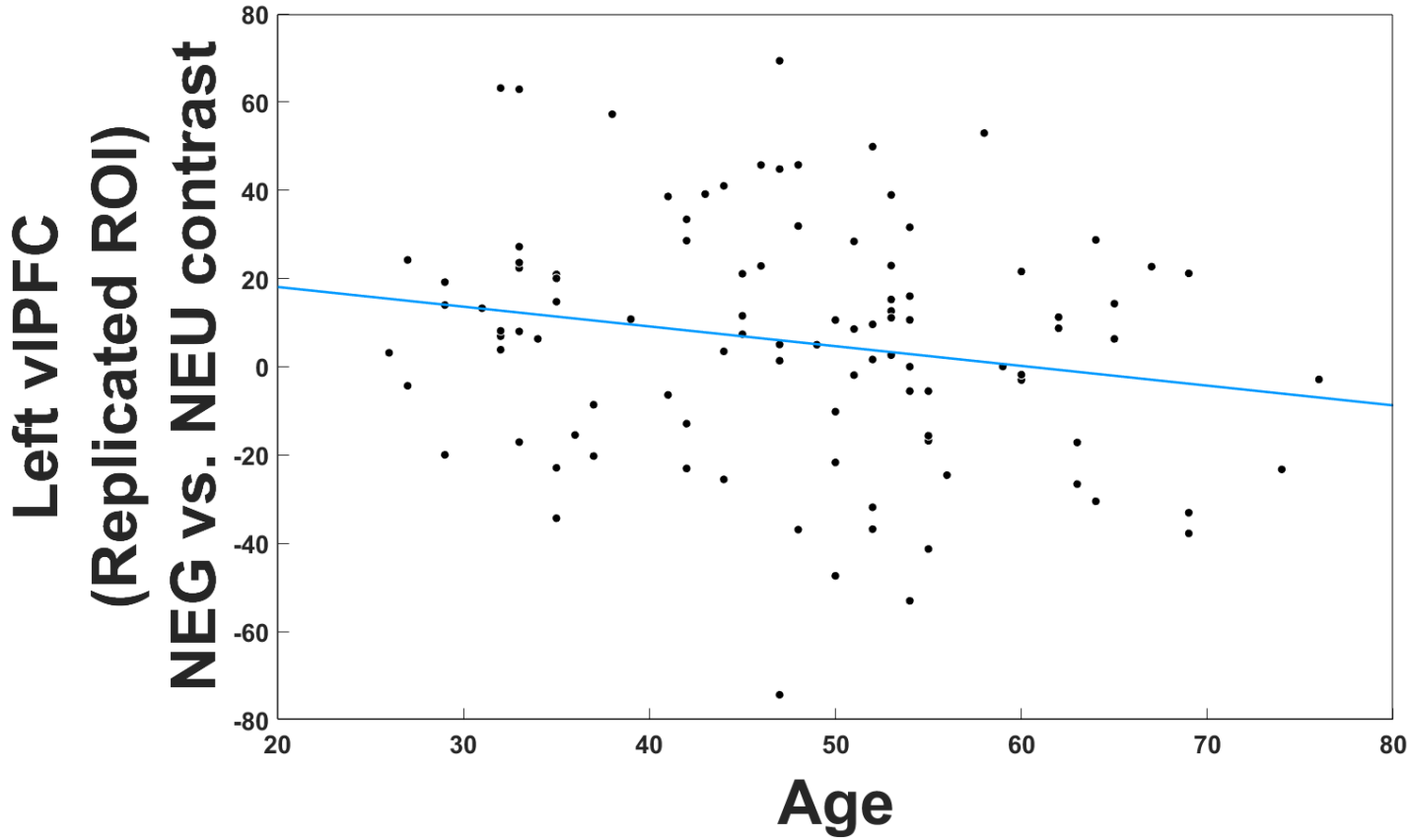

Figure 12. Scatterplot depicting the relationship between age and the BOLD signal difference between negative and neutral IAPS picture periods in the vlPFC as defined by van Reekum and colleagues (2018). Age was significantly negatively associated with left vlPFC BOLD signal during negative (NEG) vs. neutral (NEU) IAPS picture periods. The regression line is included in blue.

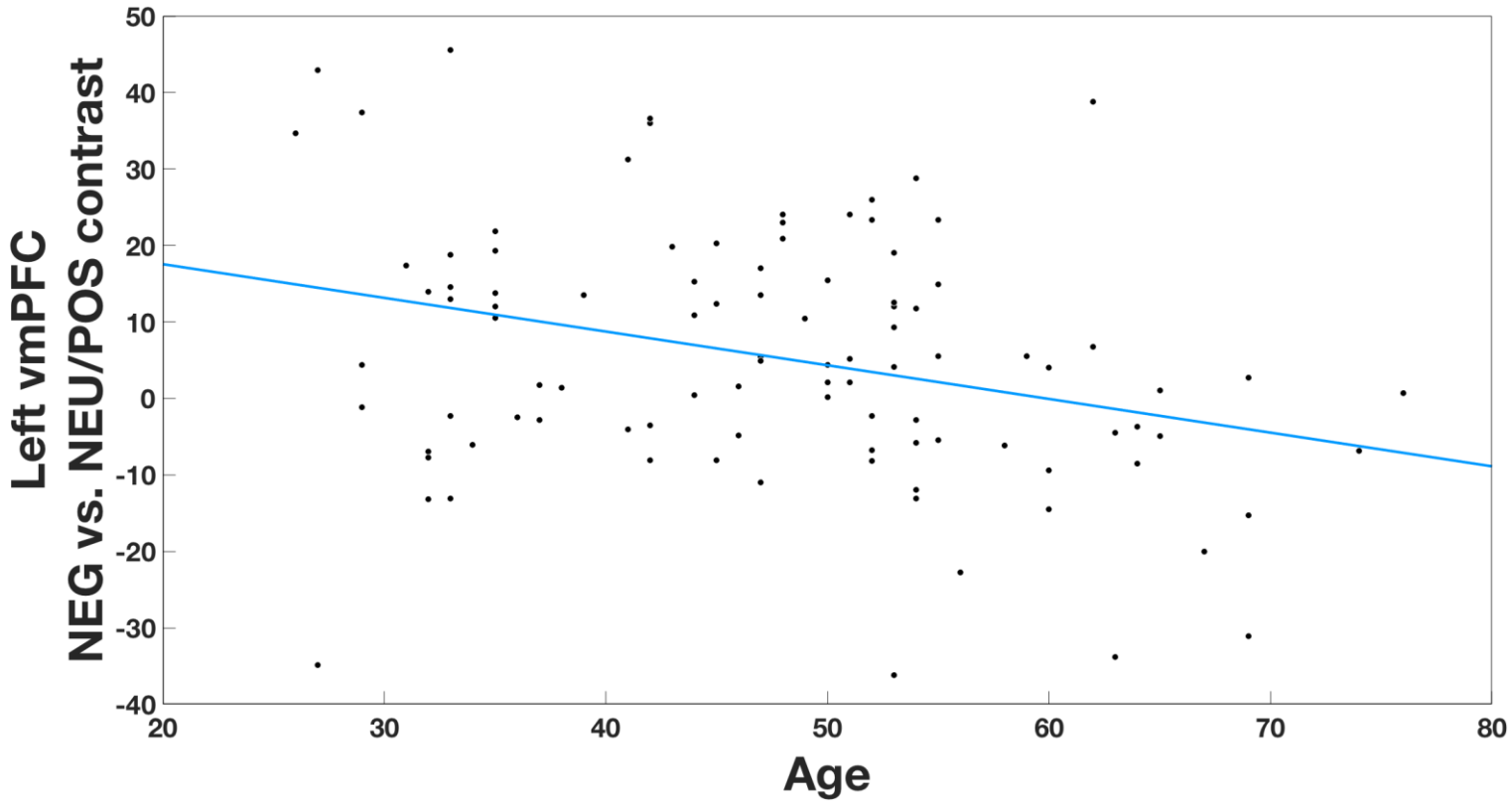

Figure 13. Scatterplot depicting the relationship between age and the BOLD signal intensity difference between negative, and neutral and positive IAPS picture periods in the left vmPFC. Age was significantly negatively associated with left vmPFC BOLD signal during negative (NEG) vs. neutral/positive (NEU/POS) IAPS picture periods. The regression line is included in blue.

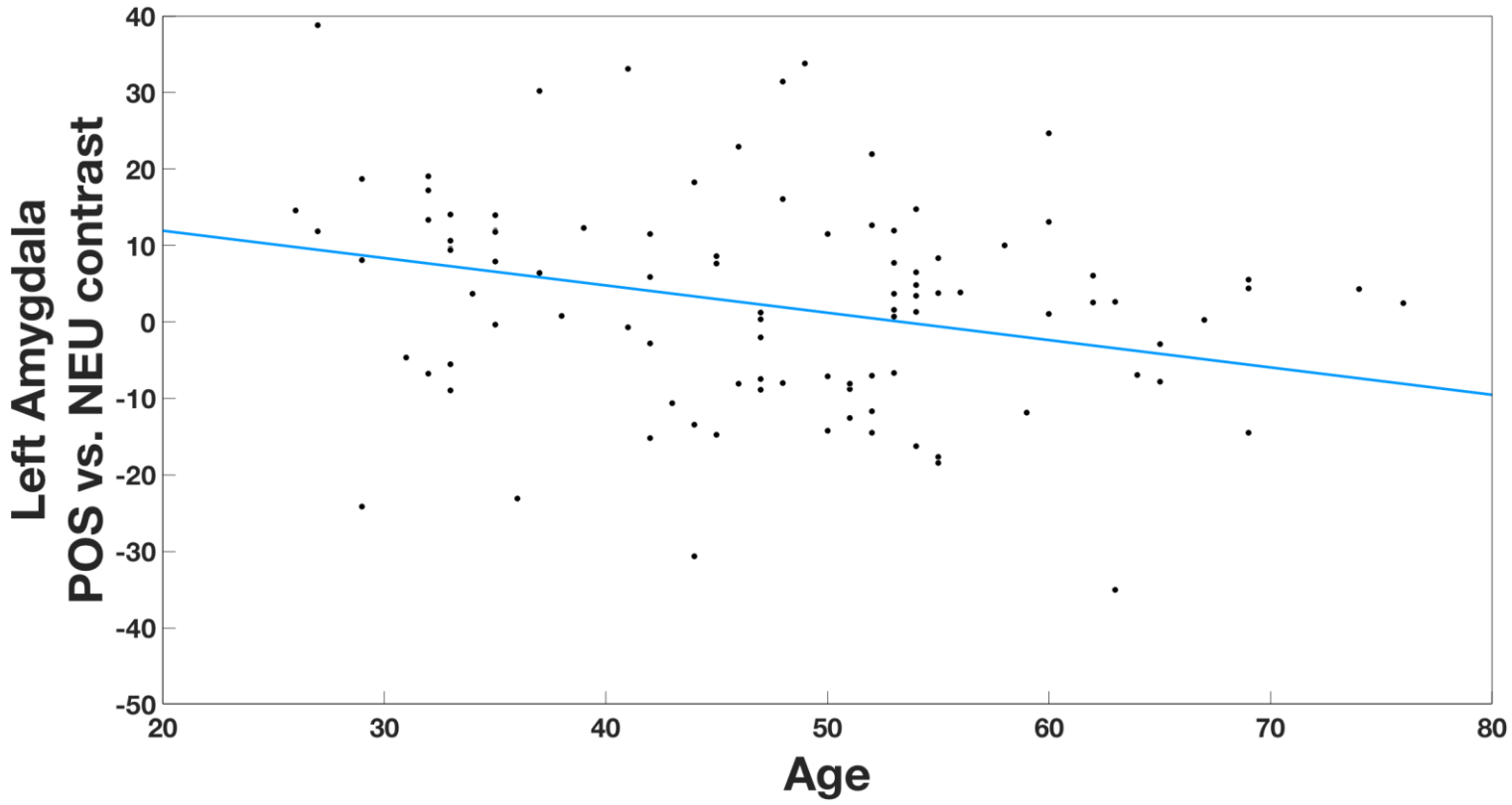

Figure 14. Scatterplot depicting the relationship between age and the BOLD signal difference between positive and neutral IAPS picture periods in the left Amygdala. Age was significantly negatively associated with left Amygdala BOLD signal during positive (POS) vs. neutral (NEU) IAPS picture periods. The regression line is included in blue.

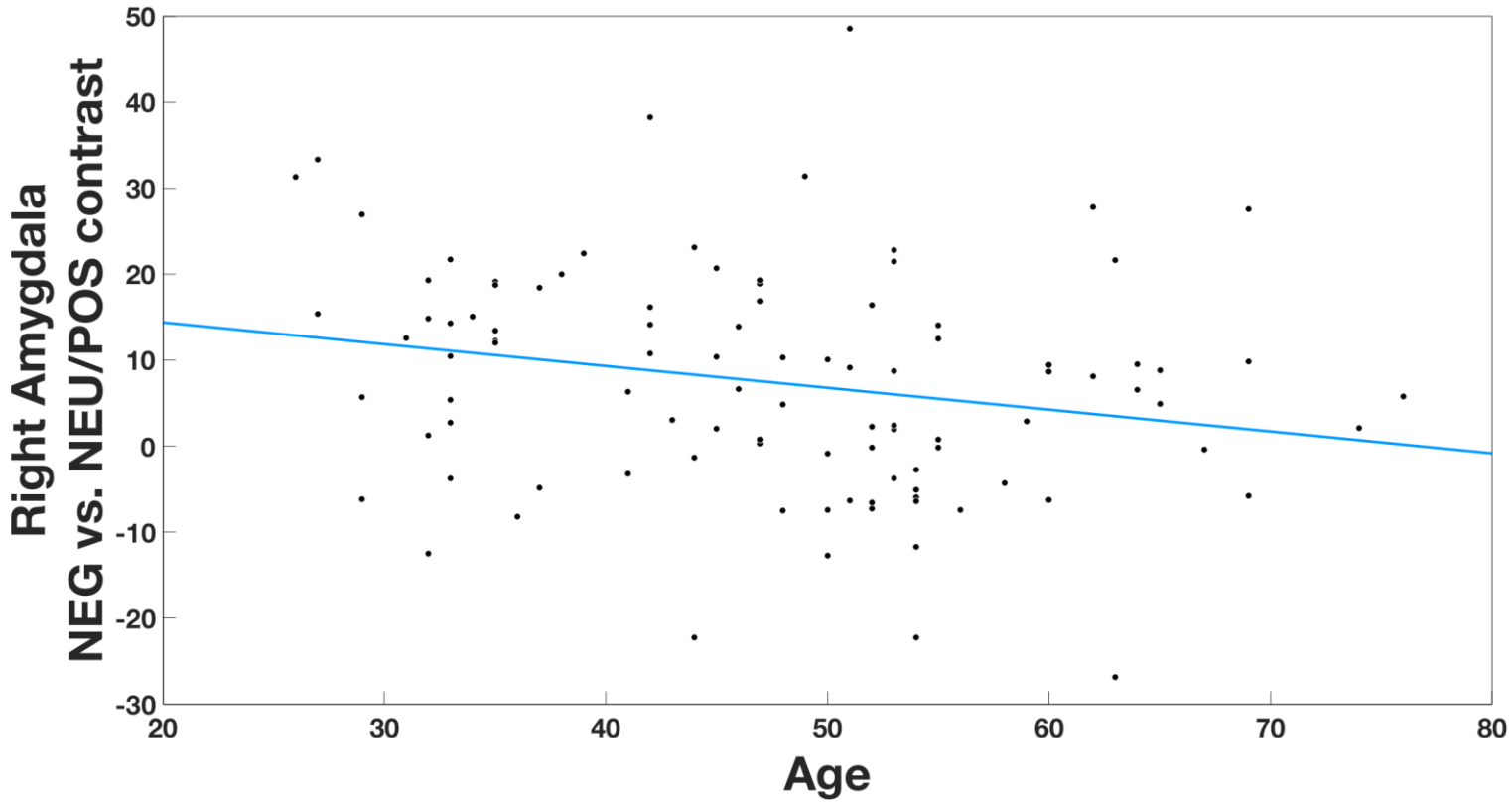

Figure 15. Scatterplot depicting the relationship between age and the BOLD signal difference between negative, and neutral and positive IAPS picture periods in the right Amygdala. Age was significantly negatively associated with right Amygdala BOLD signal during negative (NEG) vs. neutral/positive (NEU/POS) IAPS picture periods. The regression line is included in blue.

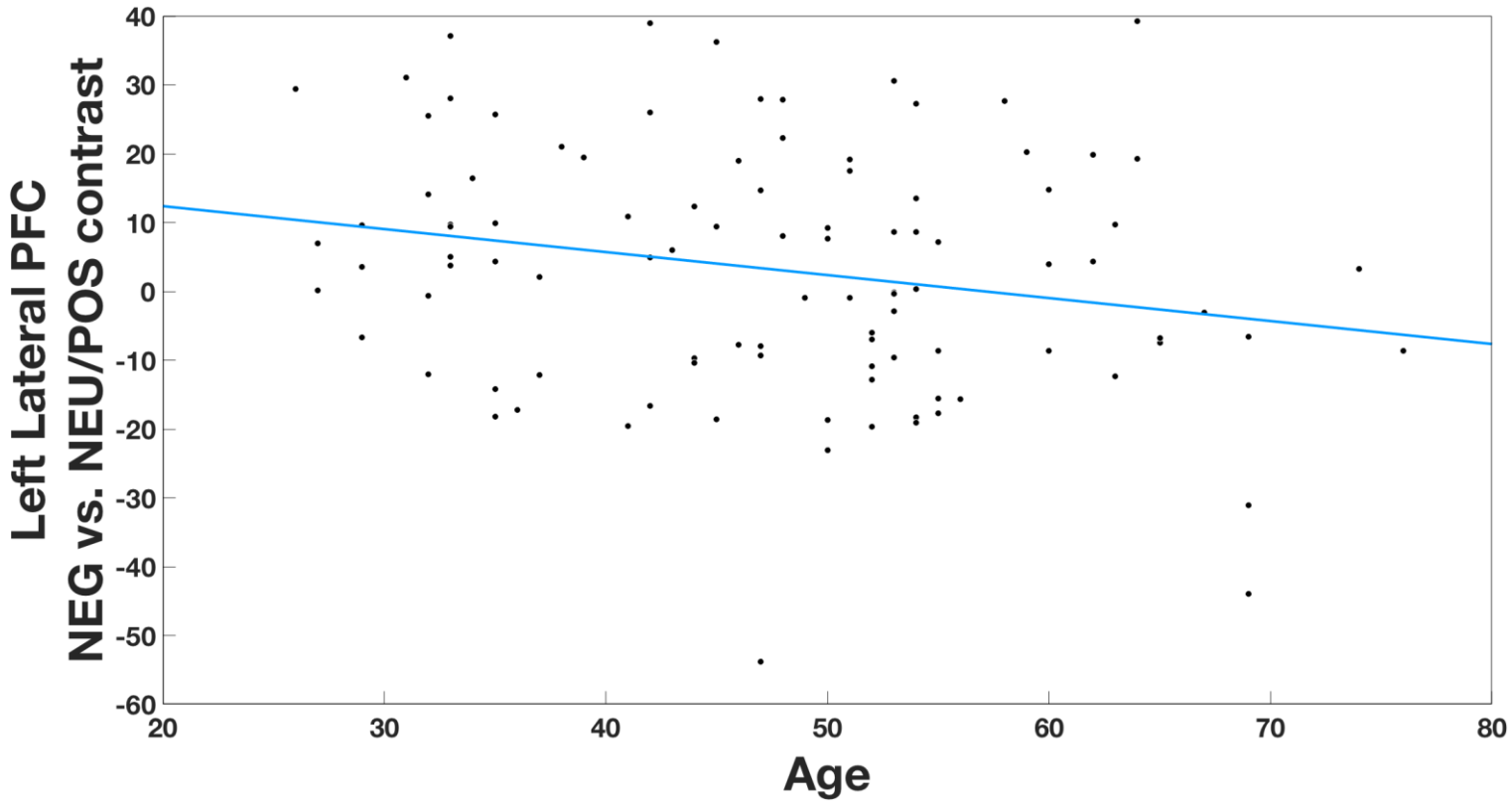

Figure 16. Scatterplot depicting the relationship between age and the BOLD signal difference between negative, and neutral and positive IAPS picture periods in the left lateral PFC. Age was significantly negatively associated with left lateral PFC BOLD signal during negative (NEG) vs. neutral/positive (NEU/POS) IAPS picture periods. The regression line is included in blue.

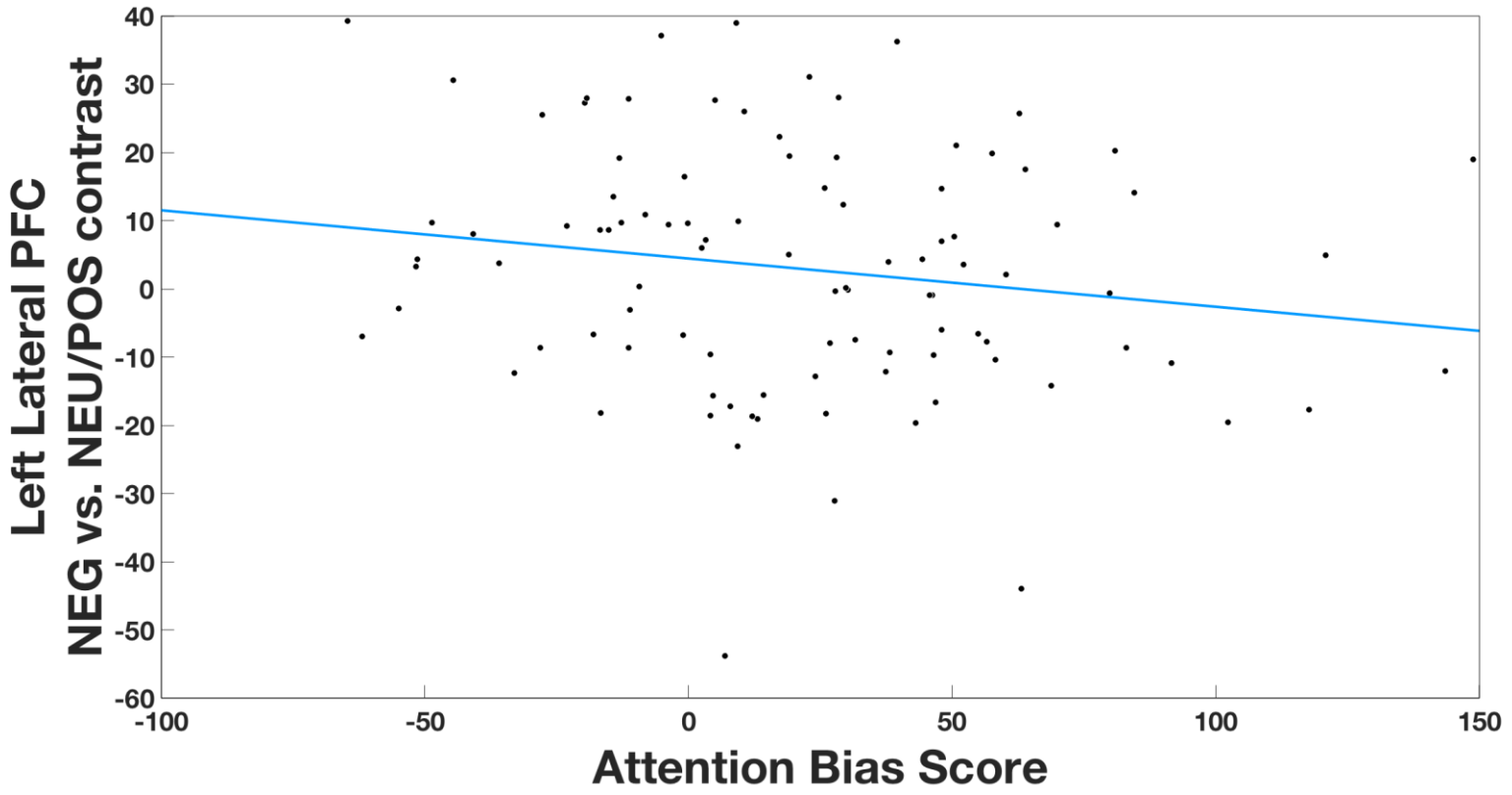

Figure 17. Scatterplot depicting the relationship between attention bias scores and the BOLD signal difference between negative, and neutral and positive IAPS picture periods in the left lateral PFC. Attention bias was significantly negatively associated with left lateral PFC BOLD signal during negative (NEG) vs. neutral/positive (NEU/POS) IAPS picture periods. The regression line is included in blue.

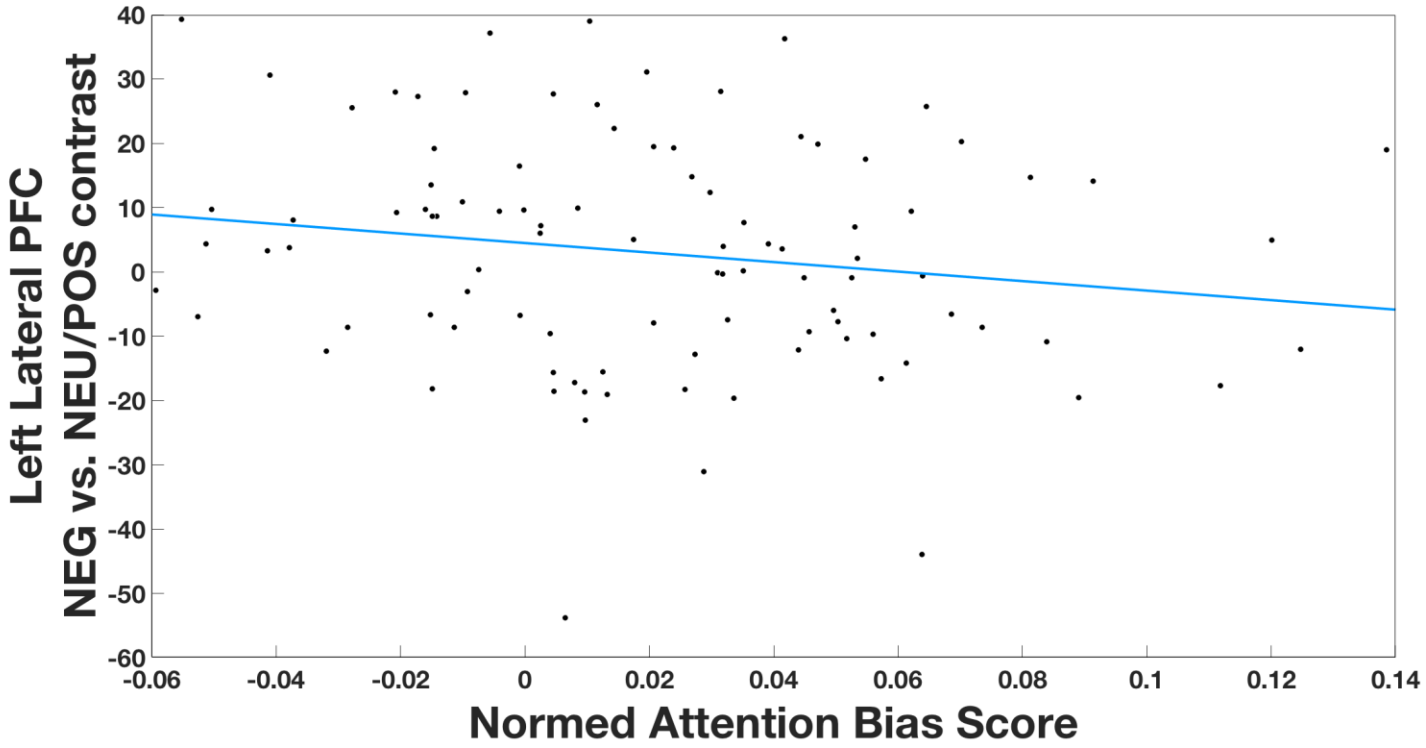

Figure 18. Scatterplot depicting the relationship between normed attention bias scores and the BOLD signal intensity difference between negative, and neutral and positive IAPS picture periods in the left lateral PFC. Normed attention bias was significantly negatively associated with left lateral PFC BOLD signal during negative (NEG) vs. neutral/positive (NEU/POS) IAPS picture periods. The regression line is included in blue.

Table 1. Results of simple linear regressions with age as the predictor and differences in BOLD signal between negative and neutral IAPS picture periods in the left vlPFC and vmPFC as dependent variables (replicated from van Reekum et al., 2018). Age was significantly negatively associated with left vmPFC BOLD signal during negative vs. neutral IAPS picture period and during negative vs. neutral/positive IAPS picture period and had a trending negative association with vlPFC for the same contrast.

Dependent variable	Independent variable	*B*	*SE*	*t*	*p*
Left vmPFC (Neg vs Neu contrast)	Intercept	22.077	10.303	2.143	.035
	Age	-.542	.21	-2.579	.011
Left vmPFC (Neg vs Neu/Pos contrast)	Intercept	10.994	8.881	1.238	.219
	Age	-.41	.181	-2.264	.026
Left vlPFC (Neg vs Neu contrast)	Intercept	27.04	11.251	2.403	.018
	Age	-.447	.23	-1.948	.054

Table 2. Results of simple linear regressions with age as the predictor and left vmPFC BOLD signal intensity differences between negative and neutral IAPS picture periods, positive and neutral IAPS picture periods, and negative, and neutral and positive IAPS picture periods as dependent variables. Age was significantly negatively associated with two of these three BOLD signal contrasts in the left vmPFC.

Dependent variable	Independent variable	*B*	*SE*	*t*	*p*
Left vmPFC (Neg vs Neu contrast)	Intercept	25.202	8.427	2.99	.004
	Age	-.459	.172	-2.67	.009
Left vmPFC (Pos vs Neu contrast)	Intercept	27.429	7.751	3.539	.001
	Age	-.421	.158	-2.662	.009
Left vmPFC (Neg/Pos vs Neu contrast)	Intercept	20.825	8.558	2.433	.017
	Age	-.342	.175	-1.958	.053

Table 3. Results of simple linear regressions with age as the predictor, right amygdala BOLD signal intensity differences between negative and neutral IAPS picture periods and between negative and positive, and neutral IAPS picture periods, as well as left amygdala BOLD signal intensity differences between positive and neutral IAPS picture periods as dependent variables. Age was significantly negatively associated with two of these BOLD signal contrasts in the right and left amygdala.

Dependent variable	Independent variable	*B*	*SE*	*t*	*p*
Right Amygdala (Neg vs Neu contrast)	Intercept	15.32	6.034	2.539	.013
	Age	-.234	.123	-1.9	.06
Right Amygdala (Neg/Pos vs Neu contrast)	Intercept	19.474	5.413	3.597	.001
	Age	-.254	.11	-2.296	.024
Left Amygdala (Pos vs Neu contrast)	Intercept	19.093	6.92	2.759	.007
	Age	-.358	.141	-2.533	.013

Table 4. Results of simple linear regressions with age as the predictor and left lateral PFC BOLD signal intensity differences between negative and neutral IAPS picture periods, negative and positive IAPS picture periods, and negative, and neutral and positive IAPS picture periods as dependent variables. Age was significantly negatively associated with two of these three BOLD signal contrasts in the left lateral PFC.

Dependent variable	Independent variable	*B*	*SE*	*t*	*p*
Left lateral PFC (Neg vs Neu contrast)	Intercept	20.825	8.558	2.433	.017
	Age	-.342	.175	-1.958	.053
Left lateral PFC (Neg vs Pos contrast)	Intercept	16.837	7.683	2.192	.031
	Age	-.316	.157	-2.015	.047
Left lateral PFC (Neg vs Neu/Pos contrast)	Intercept	19.078	7.376	2.587	.011
	Age	-.334	.151	-2.219	.029

Table 5. Results of simple linear regressions with emotional attention bias scores and normed emotional attention bias scores as predictors and left lateral PFC BOLD signal differences between negative, and neutral and positive IAPS picture periods as the dependent variable. Age was significantly negatively associated with all three BOLD signal contrasts in the left lateral PFC.

Dependent variable	Independent variable	*B*	*SE*	*t*	*p*
Left lateral PFC (Neg vs Neu/Pos contrast)	Intercept	4.685	1.872	2.503	.014
	RT Bias	-.079	.035	-2.262	.026
Left lateral PFC (Neg vs Neu/Pos contrast)	Intercept	4.473	1.838	2.434	.017
	Normed RT Bias	-73.899	32.283	-2.289	.024

Table 6. Activation clusters yielded by a whole-brain voxelwise analysis, using a one-regressor (mean across participants) general linear model. Z-threshold was 3.1.

Contrast*	Area**	H	MNI (mm)			Z Statistics
			x	y	z	
Neg > Neut	Lateral Occipital	L	-50	-70	14	9.87
	Lateral Mid Front Gyr	R	42	20	28	6.1
	Lateral Orbital Front	L	-42	26	-14	6.41
	Medial Sup Front Gyr	L	-4	50	28	6.33
	Sup Parietal Lobule	R	30	-46	48	5.57
	Midbrain		-2	-30	-4	5.81
	Amygdala	R	22	-4	-16	6.43
	Lateral Precentral Gyr	L	-46	2	34	5.04
	Amygdala	L	-18	-4	-12	6.22
	Thalamus	L	-6	-14	6	4.52
	Sup Temporal Gyr	R	50	-6	-16	5.16
	Cerebellum	R	22	-40	-44	4.55
	Precentral Gyr	L	-38	-2	48	4.66
	Precuneous	R	8	-56	54	4.29
	Precuneous	R	2	-54	16	4.32
Neg > Pos	Lateral Inf Occipital	L	-44	-70	2	7.75
	Lateral Occipital	R	34	-80	30	6.77
	Temp Occip Fusiform	R	30	-46	-8	8.73
	Lateral Mid Front Gyr	R	44	10	34	5.6
	Supramarginal Gyr	L	-58	-32	36	5.16
	Lateral Inf Front Gyr	L	-46	34	12	4.63
	Lateral Inf Front Gyr	R	48	32	-4	4.39
	Precentral Gyr	L	-44	6	28	4.91
	Midbrain		4	-30	-4	4.44
	Intracalcarine	L	-12	-80	6	5.08
	Cerebellum	R	20	-80	-36	4.21
	Lateral Sup Occipital	L	-20	-62	54	4.65
	Lateral Orbital Front	L	-34	36	-12	4.44
Pos > Neg	Medial Front Lobe	R	2	56	0	6.03
	Lateral Occip	R	48	-64	44	6.46
	Precuneous	R	4	-76	44	5.56
	Occip Pole	L	-26	-100	-4	6.56
	Lateral Occip	L	-42	-60	52	5.54
	Postcentral Gyr	L	-30	-26	70	5.1
	Occip Pole	R	18	-100	-2	5.15
	Cuneal	R	4	-82	18	4.95
	Lateral Front Pole	L	-36	54	20	4.79
	Postcentral Gyr	R	12	-46	76	4.61

	Cerebellum	L	-40	-62	-42	4.96
	Precentral Gyr	L	-60	0	4	4.82
	Central Opercular	L	-50	-18	14	4.32
	Precentral Gyr	L	-2	-34	58	4.51
	Cingulate Gyr	R	4	-32	38	4
	Juxtapositional	L	0	2	48	4.46
	Lateral Mid Temp Gyr	R	58	-28	-14	5.13
Pos > Neut	Occipital Pole	L	-14	-96	-8	8.06
	Medial Front	L	-6	56	-8	5.71
	Lateral Occipital	L	-52	-68	12	7.16
	Precuneous	R	2	-56	24	4.4
	Supramarginal Gyr	L	-54	-40	32	5.15
	Postcentral Gyr	R	42	-32	44	3.89
Neg > Pos, Neut	Lateral Occipital	R	48	-68	16	8.72
	Lateral Occipital	L	-46	-70	0	9.38
	Lateral Mid Front Gyr	R	48	14	34	6.16
	Lateral Orbital Front	L	-42	26	-14	5.75
	Supramarginal Gyrus	L	-58	-34	36	6.43
	Sup Parietal Lobule	R	30	-46	48	5.57
	Midbrain		4	-30	-4	5.56
	Medial Sup Front Gyr	L	-4	50	28	5.4
	Precentral Gyr	L	-44	6	28	5.32
	Cerebellum	L	-24	-80	-34	4.9
	Amygdala	R	22	-2	-16	5.57
	Amygdala	L	-18	-6	-14	5.44
	Thalamus	R	8	-8	2	4.39
	Sup Temp Gyr	R	50	-6	-16	4.98
Neg, Pos > Neut	Lateral Occipital	L	-52	-68	14	9.54
	Lateral Mid Front Gyr	R	42	18	26	5.38
	Medial Sup Front Gyr	L	-2	52	24	6.18
	Lateral Orbital Front	L	-42	26	-14	5.63
	Lateral Sup Occipital	R	22	-62	62	4.82
	Lateral Sup Occipital	L	-26	-74	30	5.77
	Amygdala	R	20	-4	-14	6.04
	Midbrain		-4	-30	-4	5.07
	Medial Frontal Pole	L	-6	58	-6	4.56
	Sup Parietal Lobule	L	-28	-56	52	4.66
	Cerebellum	L	-24	-80	-36	4.64
	Precuneous	R	2	-54	16	3.95
	Paravermal		0	-54	-36	4.75
	Amygdala	L	-18	-4	-14	5.65
	Cerebellum	R	26	-76	-36	4.66
	Temporal Pole	R	40	14	-30	4.29
	Sup Temp Gyr	R	54	-6	-16	4.39

* Neg = Negative picture; Pos = Positive picture; Neut = Neutral picture; ** Gyr = Gyrus, Occip = Occipital, Mid = Middle, Sup = Superior, Inf = Inferior, Front = Frontal; Temp = Temporal.