Structural and functional networks involved in empathy for positive and negative emotions in late adulthood

Abbreviated title: Empathy and aging

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Abstract

Empathy, among other social-cognitive processes, changes across adulthood. More specifically, cognitive components of empathy (understanding another's perspective) appear to decline with age, while findings for affective empathy (sharing another's emotional states) are rather mixed. Structural and functional correlates underlying cognitive and affective empathy in aging and the extent to which valence affects empathic response in the brain and behavior are not well understood yet. To fill these research gaps, younger and older participants completed a modified version of the Multifaceted Empathy Test, which measures both cognitive and affective empathy. Adopting a multimodal imaging approach and applying multivariate analysis, the study found that for cognitive empathy to negative emotions regions of the salience network, including the anterior insula and anterior cingulate, were more involved in older than younger participants. For affective empathy to positive emotions, in contrast, younger and older participants recruited a similar brain network including main nodes of the default mode network. Additionally, increased structural integrity (fractional anisotropy values) of the posterior, but not the anterior, cingulum bundle was related to activation of default mode regions during affective empathy for positive stimuli in both age groups. These findings provide novel insights into the functional networks subserving cognitive and affective empathy in younger and older adults and highlight the importance of considering valence in empathic response in aging. Further this study, for the first time, underscores the role of the posterior cingulum bundle in higher-order social-cognitive processes such as empathy in aging.

Keywords: empathy, aging, salience network, default mode network, multivariate, cingulum bundle

Introduction

Mounting evidence suggests age-related change in social-cognitive capacities including perception of eye gaze (Slessor et al., 2010; Ziaei et al., 2016), emotional facial expression (Ruffman et al., 2008), and theory of mind (Henry et al., 2013). Compared to other components of social cognition, empathy has received considerably less attention in aging research. Furthermore, the few existing studies on age-related differences in empathic response have almost exclusively used self-report and have captured more trait-like aspects of the construct (e.g., using the Interpersonal Reactivity Index; Davis, 1983). These previous studies largely agree that aging is associated with decline in cognitive empathy, the ability to decode and understand another's perspective (Beadle & de la Vega, 2019; Henry et al., 2013). However, evidence is less clear for affective empathy, i.e., the affective sharing of another's emotional states (Singer & Lamm, 2009), for which some studies suggest no age-related differences (Bailey et al., 2008; Beadle et al., 2012) while other studies support an increase with age (Grühn et al., 2008; O'Brien et al., 2012).

Even more sparse are studies measuring state empathy, specifically in aging, for example by using experimentally induced alterations in the state of affective empathy. In particular, Sze and colleagues (2012) manipulated empathic response by showing uplifting or distressing films and reported an age-related linear increase in empathic concern and personal distress in response to both types of films. Similarly, Bailey et al. (2018) found age-related increased emotional distress and reactivity towards another's pain, and this enhanced affective empathy predicted prosociality (i.e., willingness to help). Finally, Beadle et al. (2015) did not find evidence for age-group differences in affective empathy or personal distress in response to cancer patients describing

their experiences with the disease. This currently limited and mixed knowledge base on age effects in cognitive and affective empathy warrants additional research.

Impact of valence on empathic response in aging

Over the last two decades robust evidence suggests prioritized processing of positive over negative information among older (compared to younger) adults. This effect is reflected in greater attention to, and memory for, positive over negative stimuli and has been termed the "positivity effect" in aging (Mather & Carstensen, 2003; Reed & Carstensen, 2012; Ziaei & Fischer, 2016; Ziaei et al., 2015). The positivity effect has been interpreted as a motivational, goal-oriented shift with age. Closely related to this concept of a positivity effect in aging is the motivational empathy account, also referred to as 'empathic concern' (Weisz & Zaki, 2018). According to this account, an observers' motivation/social goals can manifest in the reduction or intensification of empathy towards a target.

However, to date understanding of the impact of valence on empathy in aging is still very limited. First findings in younger adults support the distinction of empathic response to positive vs. negative stimuli, known as positive vs. negative empathy, respectively (Morelli et al., 2015). Previous work suggests that people use the emotion expressed by others as a social signal to interpret what others are feeling (Van Kleef, 2009). Thus, based on robust evidence of an age-related shift in processing positive over negative information (i.e., positivity effect), and in line with the motivational account of empathy, it is reasonable to assume that older adults' empathic response is particularly impacted by valence of to-be-processed information.

Neural correlates of empathy

The anterior insula, mid and dorsal anterior cingulate gyrus (ACC), and temporo-parietal junction (TPJ) have been identified as key brain regions involved in empathy (Bernhardt &

Singer, 2012; Bzdok et al., 2012b; Decety & Jackson, 2006; Lamm et al., 2011). However, to date, only two studies have investigated the neural substrates underlying empathy in older adults. In particular, Chen and colleagues (2014) asked participants to rate their feelings towards another's pain and found age-related decrease in activation of insula and anterior cingulate during this task. Additionally, Riva et al. (2018) reported reduced insula activity during both pleasant and unpleasant touch using a visuotactile stimulation paradigm among older female participants. However, while meta-analyses support the importance of insula and anterior cingulate as a core "empathy network", a distinction between affective-perceptual vs. cognitive-evaluative empathy networks has been proposed (Bellucci et al., 2020; Fan et al., 2011). In this context, the anterior insula has been suggested to be involved in the affective-perceptual component of empathy and the anterior cingulate in the cognitive-evaluative empathy. Furthermore, as empathy is a complex and multidimensional process, it is likely that empathic response activates large-scale brain networks and not just individual regions, but a multivariate approach to the study of empathy is currently still limited.

Structural pathways in empathy

White matter tracts, such as the cingulum bundle which links the frontal lobe with the precuneus, posterior cingulate cortex, hippocampus, and parahippocampus (Wakana et al., 2004), are believed to be critical in attention, memory, executive functioning, and emotional processing (Keedwell et al., 2016; van den Heuvel et al., 2008; Wu et al., 2016). Also, more integrity in the anterior subdivision of the cingulum bundle was associated with better cognitive control in older adults (Metzler-Baddeley et al., 2012). However, structural pathways that subserve empathic responding have not been well investigated yet, and currently unknown is the extent to which

integrity of the anterior, as well as the posterior, cingulum bundle facilitates higher-order social-cognitive processes, such as empathy, among older adults.

Current study

To address the research gaps outlined above and to integrate previously parallel lines of work, the present study had three major aims: to examine the extent to which functional activation involved in both cognitive and affective empathy *(i)* differed between younger and older adults, (ii) also in interaction with stimulus, and *(iii)* were related to cingulum bundle microstructure. Here, younger and older adults completed a modified version of the Multifaceted Empathy Test (MET) (Dziobek et al., 2011) that included positive, negative, and neutral images to allow the systematic investigation of valence effects on empathic response (Mazza et al., 2015). Both structural and functional brain images were acquired to determine the association between functional network activation during the empathy task and white matter tract integrity known to play a role in emotional processing and aging.

In particular, we hypothesized that older relative to younger participants would show poorer performance and that the age groups would display differential recruitment of brain networks (e.g., the limbic system; Yu & Chou, 2018), during cognitive empathy (*Hypothesis 1a*; Beadle & de la Vega, 2019). In contrast, we predicted that performance during affective empathy would be comparable between younger and older participants (Beadle & de la Vega, 2019), reflected in equal engagement of empathy-related brain regions (such as the insula and the anterior cingulate cortex; Singer & Lamm, 2009) (*Hypothesis 1b*). We further expected that the age groups would differ in their recruitment of brain networks in response to negative and positive stimuli, with reduced activity of the salience network for negative (*Hypothesis 2a*) and enhanced or equal activity of the default mode network for positive stimuli (*Hypothesis 2b*) among older

participants. These predictions were based on evidence that positive and negative empathy selectively activate regions associated with positive (e.g., ventromedial prefrontal cortex) and negative (e.g., anterior insula, dorsal anterior cingulate cortex) affect, respectively (Morelli et al., 2015; Ziaei et al., 2019). We have previously demonstrated that positive affect was associated with activation in regions within the default mode network in older adults (Ziaei et al., 2017). To our knowledge, however, no studies to date have compared neural correlates of positive vs. negative stimuli between younger and older adults during the empathy task. Thus, our predictions build on research in emotion recognition that suggests that regions such as the vmPFC and posterior cingulate cortex to be involved during the positive stimuli and regions such as insula and anterior cingulate to be involved during negative stimuli.

Our analysis regarding brain structure-function links, finally, build on evidence pertaining to a posterior-to-anterior shift in aging (Davis et al., 2008). This model suggests that in older compared to younger adults, anterior brain regions (e.g., prefrontal cortex) are more activated than posterior brain regions (e.g., sensory and visual cortex) across a variety of cognitive tasks. Thus, here we explored age-related differences in the anterior and posterior subdivision of the cingulum bundle in their association with functional activation during both cognitive and affective (positive and negative) empathy. We anticipated that higher fractional anisotropy of the anterior cingulum bundle would be related to functional activation during the cognitive empathy and posterior cingulum to be related to the functional activation of the affective empathy among older adults.

Method

Participants

Twenty-six younger and 25 older adults participated in this study. Due to large head movement (> 1.5mm), two younger participants were excluded, leaving 25 younger (*M* = 21.81, *SD* = 4.06; 13 females) and 24 older (*M* = 71.52, *SD* = 3.80; 14 females) participants for final data analysis. All younger participants were University of Queensland undergraduate students who were reimbursed either with course credits or AUD$20 per hour. Older participants were volunteers from the community, recruited through advertising in public notice boards of different clubs, libraries, churches, and the University of Queensland's Aging Mind Initiative. Older participants were reimbursed with AUD$20 per hour.

All participants were right-handed, English speakers who had normal or corrected-to-normal vision using magnetic resonance imaging (MRI) compatible glasses, and no history of diagnosed psychiatric illnesses (such as depression and anxiety), no history of medication for psychiatric illnesses, no cardiovascular disease, head/heart surgery, or neurological impairment (e.g., epilepsy). The age groups were comparable in years of education and gender distribution (Table 1). All older participants scored above the recommended cut-off of 27 (*M* = 28.76, *SD* = 1.26) on the Mini Mental State Examination (Folstein et al., 1975).

Procedure

The experiment was approved by the Royal Brisbane and Women's Hospital and the University of Queensland Research Ethics Committees. All participants provided written informed consent prior to enrollment. The study comprised a 1-hour MRI session, followed by a 2-hour behavioral/neuropsychological assessment on the same day. Prior to the MRI, participants received verbal instruction about the MET (described next) and worked on practice trials for

familiarization with the trial timing and task sequence. After the MRI, participants completed a series of background measures (described below), were debriefed, and received reimbursement.

Multifaceted Empathy Task (MET)

We used a modified version of the MET (Dziobek et al., 2011). As depicted in Figure 1, the MET consists of naturalistic images of human faces. The tasks comprised three experimental conditions: cognitive empathy, affective empathy, and age perception control. For the cognitive empathy condition, participants were asked to identify "what kind of emotion does this person feel?" by choosing "positive", "negative", or "neutral." For the affective empathy condition, participants were asked to think about their feeling towards the person depicted and rate "how strong is the emotion you feel about this person?" by choosing "low", "average", and "high". This question aimed to evoke emotional responses to the depicted person rather than inferring the emotion experienced by that person (as in the cognitive empathy condition). For the age perception control condition, participants were asked to identify "what is the age of this person?" depicted on the picture by choosing "child", "adult", and "elderly". This condition was used to control for higher-order cognitive processes involved in processing of the specific stimuli used in this task. Responses were recorded using three keys on an MRI-compatible response box. To reduce working memory load, all response options remained on the screen.

Following Mazza et al. (2015), positive (happy), negative (sad, angry), or neutral faces were presented in each of the three experimental conditions. In particular, we included seven pictures of the same valence in each of the three experimental conditions, with each image presented for six seconds, for a total duration of 42 seconds per block. Compared to the original task (Mazza et al., 2015), we shortened block length from 70 to 42 seconds, to improve the brain signal (Huettel et al., 2014). Pictures were selected from the original MET and supplemented by pictures from

the International Affective Picture System (Lang et al., 2008). The full list of pictures for each valence, and their original (Mezza et al., 2015) and study-specific valence and arousal ratings are presented in the Supplemental Material. The valence and arousal ratings of pictures used in this study were as follow: Negative pictures (valence: *M* = 3.14, *SD* = 1.47; arousal: *M* = 4.78, *SD* = 2.12; e.g., homeless man, crying baby, angry man, and distressed woman); positive pictures (valence: *M* = 6.98, *SD* = 1.61; arousal: *M* = 4.35, *SD* = 2.17; e.g., laughing boy, grateful girl, happy elderly woman, and pilot); and neutral pictures (valence: *M* = 5.27, *SD* = 1.45; arousal: *M* = 3.57, *SD* = 1.96; e.g., neutral faces of woman, man, and child). There were equal numbers of male and female faces in each of the three experimental conditions. Stimuli were presented in color and standardized in size to 507 x 635 pixels, against a gray background.

The task was presented in three runs. Each run included three blocks (cognitive empathy, affective empathy, and age perception conditions) of positive, negative, and neutral face images, resulting in nine blocks in total per run. The order of conditions in each run was pseudo-randomized. Positive, negative, and neutral face stimuli were counterbalanced across conditions and runs (i.e., positive pictures presented in the affective empathy condition in Run 1 were presented during the cognitive and control conditions in Run 2 and 3, respectively). We ensured that each block of positive, negative, or neutral pictures was only presented once within each run. The order of presenting each run was counterbalanced between participants. To enhance design efficiency (Huettel et al., 2014), each run included two low-level blocks, presented randomly for 42 seconds during the run and consisting of a fixation cross on gray background. In addition, a jittered fixation cross was presented between each block in each run randomly from one of the following durations: 1.5, 2, and 2.5 seconds. Each run lasted 7.7 minutes, for a total task duration

of 23.1 minutes. We used Psychtoolbox for task programming, presentation, and response recording.

[Insert Figure 1 about here]

Background measures

In the behavioral/neuropsychological test session, participants completed a series of tasks pertaining to executive functioning: the Stroop Task (Jensen & Rohwer, 1966), the abbreviated version of the Raven's Progressive Matrices (Bilker et al., 2012), the Trail Making Test (Reitan & Wolfson, 1986), and a verbal fluency measure (Newcombe, 1969). Emotional well-being was measured with the Depression, Anxiety, Stress Scale – DASS-21 (Lovibond & Lovibond, 1995). In addition, the Empathy Quotient (Baron-Cohen & Wheelwright, 2004), the Interpersonal Reactivity Index (Davis, 1983), and the Reading the Mind in the Eye test (Baron Cohen et al. (2001) measured empathy and theory of mind. As shown in Table 1, there were no differences between the two age groups in any of the background measures, with the exception of the three DASS-21 subscales, for which younger participants reported higher levels than older participants, and the personal distress subscale from the IRI, for which younger participants scored higher than older participants ($ps < 0.001$).[1]

MRI image acquisition

Functional images were acquired at the Centre for Advanced Imaging on a 3T Siemens Prisma scanner with a 32-channel head coil, using a whole-brain T2*-weighted multiband sequence (834 interleaved slices, repetition time (TR) = 612 ms, echo time (TE) = 30 ms, voxel size = 2.5 mm^3, field of view (FOV) = 190 mm, flip angle = 52°, multi-band acceleration factor =

[1] Behavioral performance was analyzed using DASS-21 and personal distress as covariates. Inclusion of these covariates did not change the results.

5). High-resolution T1-weighted images were acquired with an MP2RAGE sequence (176 slices per slab, TR = 4000 ms, TE = 2.91 ms, TI = 700 ms, voxel size = 1 mm^3, FOV = 256 mm, PAT mode = GRAPPA). Diffusion-weighted imaging sequence with two shells (shell one: TR = 4100 ms, TE = 70 ms, voxel size = 2 mm^3, number of slices =68, FoV = 244 mm, b-value: 2500 s/mm^2, 66 directions, and shell two: TR = 4100 ms, TE = 70 ms, voxel size = 2 mm^3, number of slices =68, FoV = 244 mm, b-value: 1200 s/mm^2, 33 directions). To minimize noise and head movement, participants were provided with earplugs and cushions around their head inside the head coil. Participants observed the task on a computer screen through a mirror mounted on top of the head coil.

Data Analysis

Behavioral data

We conducted a repeated measure analysis of variance (ANOVA) on mean response times with the three experimental conditions (cognitive empathy, affective empathy, age perception) and valence (positive, negative, neutral) as within-subject factors and age group (younger, older) as between-subject factor. While both response times and accuracy were collected during the task, given the block design which presented blocks of seven positive, negative, or neutral images respectively, accuracy did not vary within a block and thus was limited as an outcome variable[2]. Additionally, while we were able to assess accurate responses during the cognitive empathy and age perception conditions, during the affective empathy condition participants were instructed to indicate how strongly they felt towards the stimuli and thus were not probed on accuracy. Reaction times reflected behavioral performance in the MET task. Response times

[2] For completeness, however, results pertaining to accuracy are reported in the Supplemental Material.

were skewed as determined by the Shapiro-Wilk normality test. We therefore used log transformation for the analyses reported here.

We additionally investigated relationships between the background measures with the structural and functional measures. The results of these analyses are reported in the Supplementary Results.

fMRI

Preprocessing. T2*-weighted images were preprocessed with Statistical Parametric Mapping Software (SPM12; http://www.fil.ion.ucl.ac.uk/spm) implemented in MATLAB 2017 (Mathworks Inc., MA). Following realignment to a mean image for head-motion correction, images were segmented into gray and white matter. Images were spatially normalized into a standard stereotaxic space with a 2-mm^3 voxel size, using the Montreal Neurological Institute (MNI) template and spatially smoothed with a 6-mm^3 Gaussian Kernel.

Analyses. We used task Partial Least Squares (PLS; McIntosh et al., 1996; McIntosh et al., 2004), as implemented in PLS software running on MATLAB 2017 (The MathWorks Inc., MA), to determine age-related differences in whole-brain activity patterns for the three experimental conditions (cognitive empathy, affective empathy, age perception) and by image valence (positive, negative, neutral).

PLS is a model-free, multivariate analytical technique (for a detailed tutorial and review of PLS, see Krishnan et al. (2011)) that allows examination of the relationship between brain activity and multiple experimental conditions simultaneously and that does not require multiple comparison correction (McIntosh et al., 2004). For the whole-brain analysis, we included all three experimental conditions: cognitive empathy, affective empathy, and age perception for both age groups. PLS captures the pattern of covariance between data that are unique to the data

set without imposing arbitrary contrasts for or assumptions about the experimental conditions. PLS organizes all data from all participants and all experimental conditions into a single matrix, and by using a singular value decomposition (SVD) finds a set of orthogonal latent variables (LVs), which represent linear combinations of the original variables.

In contrast to the more commonly used General Linear Model, PLS not only considers the temporal relationship between the fMRI data and the task design but also the spatial relationship between activated voxels. As a spatio-temporal analysis method, PLS is based on the joint variance of individual voxels and is, thus, more sensitive to the covariance of the brain activity. By using PLS, our results here are not based on contrasts that show regions that are more or less engaged during one condition over another (i.e., our results do not follow the logic of the subtraction method). Rather, our results reflect changes in brain activity related to task manipulation uncovering the brain's responses to differences between the experimental conditions. Thus, our study design leverages the strengths of PLS for a novel multivariate examination of age-related differences in empathic response to positive and negative empathy.

Each LV identified with PLS delineates brain activity patterns related to the experimental conditions. Usually, the first LV accounts for the largest covariance of the data, with a progressively smaller amount of covariance for subsequent LVs. The amount of covariance accounted by an LV is referred to as singular value. Each LV consists of a spatio-temporal pattern of brain activity (referred to as voxel saliences), a set of weights that indicates the relationship between the brain activity and the experimental conditions (referred to as task saliences). Each LV contains brain scores that reflect how each participant contributed to the pattern expressed in the respective LV. A permutation test with 500 random reordering and resampling was conducted to infer the statistical significance of each LV (McIntosh et al., 1996).

Additionally, the robustness of voxel saliences was assessed with a bootstrap estimation with 100 resampling iterations (Efron & Tibshirani, 1985). Peak voxels with a bootstrap ratio (i.e., salience/standard error) $\geq$ 2.5 were considered reliable, as this approximates $p < 0.005$ (Sampson et al., 1989).

In this study, we used a block design analysis by defining, within each of the three experimental conditions (cognitive empathy, affective empathy, age perception), the onset of each block of positive, negative, and neutral stimuli, respectively. For the *Hypothesis 1* set, to determine age-related differences in brain activity patterns for cognitive and affective empathy, we included both age groups and all three experimental conditions, irrespective of valence. For the *Hypothesis 2* set, to examine the role of valence within each experimental condition, we conducted separate analyses for each of the three experimental conditions with positive, negative, and neutral valence and both age groups included in each analysis. To determine associations between structural integrity and functional network activity, we examined whether fractional anisotropy (FA values) of anterior and posterior cingulum bundle white matter tracts were correlated with functional networks activated during the MET task and whether this association varied by stimulus valence (positive, negative, neutral) and age group.

DTI

The *recon-all* command implemented in FreeSurfer (v6.0) (http://surfer.nmr.mgh.harvard.edu/) was used for the segmentation of T1-weighted images (Dale et al., 1999). The diffusion-weighted data were preprocessed to correct for head movements, eddy current distortions, and signal intensity inhomogeneities, using tools implemented in MRtrix3 (Tournier et al., 2012). DW and T1-weighted images were co-registered using boundary-based registration (Greve & Fischl, 2009). A five-tissue-type segmented image

(cortical grey matter, white matter, sub-cortical grey matter, cerebrospinal fluid, pathological tissue) was generated from the preprocessed T1-weighted images. Response functions were estimated using a multi-shell, multi-tissue algorithm, and multi-tissue constrained spherical deconvolution was applied to obtain fiber orientation distributions (FOD) (Jeurissen et al., 2014). For the reconstruction of the anterior and posterior cingulum subdivisions, we used a deterministic tractography algorithm based on spherical deconvolution, which takes the FOD image as input and samples it at each streamline step. Newton optimization was performed on the sphere from the current streamline tangent orientation to locate the orientation of the nearest FOD amplitude peak. The step size of the tracking algorithm was set to 0.5mm, with a cut-off value for the FOD amplitude of 0.05, maximum turning angle of 45°, and minimum path length of 10mm. Mean FA was calculated for each reconstructed tract, as a general marker of integrity within white matter structures, suggesting coherence within a fiber and voxel density (Beaulieu, 2002).

Tractography pipeline

Anatomical landmarks were identified on color-coded diffusion tensor maps. An exclusion region of interest (ROI) was drawn across the mid-sagittal plane to exclude interhemispheric projections. Further exclusion ROIs were drawn to exclude tracts that deviated from the anatomy of the cingulum bundle. All tracts were reconstructed in the left and right hemisphere. The anterior and posterior subdivisions were reconstructed as described previously (Metzler-Baddeley et al., 2012) with minor modifications: The anterior cingulum was defined as the cingulum segment rostral to the anterior commissure. The seed ROI was drawn in line with the anterior commissure in the coronal plane. One inclusion ROI was placed in the slice where the most inferior part of the genu was identified in the axial plane, and another inclusion ROI was

drawn in the coronal plane where the most posterior part of the genu was visible. The posterior cingulum was defined as the cingulum segment caudal to the posterior commissure. The seed ROI was placed in line with the posterior commissure in the coronal plane. One inclusion ROI was drawn in the slice where the most inferior part of the splenium was identified in the axial plane, and another inclusion ROI was placed in the coronal plane where the most anterior part of the splenium was visible.

We also included the uncinate fasciculus tract as a control in our structural analyses. The reconstruction of the uncinate fasciculus followed previous report (Metzler-Baddeley et al., 2011). In short, a seed ROI was placed on a coronal slice, where the uncinate enters the frontal lobe rostral to the genu of the corpus callosum. An inclusion ROI was drawn on an axial slice where the uncinate enters the temporal lobe region. An exclusion ROI was drawn across a coronal slice at the level of the pons, to exclude fibres from the inferior frontal-occipital fasciculus. Statistical analyses on the age-related differences between FA values in the selected white matter tracts were conducted and results are reported in the Supplementary Results.

Structure-function analysis

We followed previous approaches (Dzafic et al., 2019; Ziaei et al., 2020) for our structure-function analyses. Our analysis procedure is outlined in Figure 2. In particular, to determine (age-differential) associations between structural integrity (FA values) of the cingulum bundle tracts and whole-brain activation during the MET task we performed separate PLS analyses for each white matter structure (i.e., the anterior subdivision of the cingulum tract and the results reflect correlations between a) brain scores and FA values of the anterior cingulum, b) brain scores and FA values of the posterior cingulum, separately, and separate for the left and right hemisphere. Brain scores for each participant were correlated with the cingulum tract FA values

for the cognitive and affective empathy condition (in separate analyses) including positive, negative, and neutral images in the models. The correlations were acquired for each participant within each age group. These analyses aimed to examine the relation between the functional brain activity pattern and FA values of white matter tracts in both age groups.

[Insert Figure 2 about here]

Results

Behavioral performance

Response times

All three main effects were significant. The main effect for experimental condition ($F(2,96) = 89.54$, $p < 0.001$, $\eta_p^2 = 0.65$) showed that participants overall responded slower in the affective than the cognitive condition ($M_{(\text{affective})} = 2.20$, $SD = 0.54$; $M_{(\text{cognitive})} = 1.93$, $SD = 0.41$). The main effect for valence ($F(2,96) = 40.95$, $p < 0.001$, $\eta_p^2 = 0.46$) showed that participants overall responded faster to positive than negative stimuli ($M_{(\text{positive})} = 1.70$, $SD = 0.36$; $M_{(\text{negative})} = 1.87$, $SD = 0.35$). The main effect for age group ($F(1,48) = 13.15$, $p = 0.003$, $\eta_p^2 = 0.21$) revealed that overall older participants responded slower than younger participants ($M_{(\text{older adults})} = 2.03$, $SD = 0.32$; $M_{(\text{younger adults})} = 1.71$, $SD = 0.29$) (Figure 3).

A significant experimental condition by age group interaction ($F(2,96) = 8.36$, $p < 0.001$, $\eta_p^2 = 0.14$) indicated that older compared to younger participants responded slower during affective ($t(49) = 2.61$, $p = 0.012$, $d = 0.74$), and particularly during cognitive ($t(48) = 5.33$, $p < 0.001$, $d = 1.53$), empathy, while the age groups did not differ in response time during the age perception control condition ($t(49) = 0.95$, $p = 0.34$, $d = 0.27$). A significant valence by age group interaction ($F(2,96) = 4.34$, $p = 0.016$, $\eta_p^2 = 0.08$) showed that relative to younger participants,

older participants responded slower to negative than positive stimuli ($t_{older\ adults}$ (23) = 4.58, p < 0.001, d = 1.9). A significant experimental condition by valence interaction (F(4,192) = 36.53, p < 0.001, η_p^2 = 0.43) finally suggested that participants responded slower to neutral than emotional stimuli during cognitive empathy (t(49) = 9.66, p < 0.001, d = 2.76), while response time was not different during either the affective empathy or the age perception control condition (all ps > 0.05).

[Insert Figure 3 about here]

Whole-brain activity pattern

Age-related differences in cognitive and affective empathy (Hypotheses 1a&b). This analysis resulted in two significant LVs. The first LV accounted for 48% covariance of the data (p < 0.001). This brain pattern included bilateral insula, bilateral parahippocampus, right superior frontal gyrus, left superior temporal gyrus, right anterior cingulate, left medial frontal gyrus, bilateral precuneus, and bilateral posterior cingulate (Figure 4A). This network was engaged more by older than younger participants and similarly so across all three experimental conditions (Figure 4B).

The second LV accounted for 26% of the covariance of the data (p < 0.001). This mainly left-sided brain pattern included left inferior frontal gyrus, left superior gyrus, left medial frontal gyrus, left inferior parietal lobe, bilateral anterior cingulate, left supramarginal gyrus, left superior temporal gyrus, left middle temporal gyrus, and bilateral insula (Figure 4C). Both age groups engaged this network similarly during the affective empathy condition (Figure 4D). Additionally, this LV included another pattern, which corresponded to the age perception control condition similarly in both age groups and included the right pre and post central gyrus, bilateral inferior parietal lobe, and right precuneus.

[Insert Figure 4 about here]

Age-related differences in valence effects on cognitive and affective empathy (Hypotheses 2a&b). The analysis pertaining to cognitive empathy resulted in one significant LV that accounted for 39% of covariance of the data (p = 0.002). This network included bilateral inferior frontal gyrus, anterior cingulate, bilateral superior temporal gyrus, bilateral superior frontal gyrus, medial frontal gyrus, and bilateral precentral gyrus regions (Figure 5A). This network was positively correlated with cognitive empathy to negative and neutral stimuli only in older participants (Figure 5B).

The analysis pertaining to affective empathy also resulted in one significant LV which accounted for 51% of covariance of the data ($p < 0.001$). This network included bilateral middle and superior frontal gyrus, posterior cingulate, precuneus, lingual gyrus, inferior parietal lobe, and superior temporal gyrus (Figure 5C). This wide-spread network was positively correlated with the affective empathy to positive stimuli in both younger and older participants, and additionally to neutral stimuli in older participants (Figure 5D).

The control analysis pertaining to age perception resulted in one significant LV that accounted for 45% of covariance of the data ($p = .012$). This network included anterior and posterior cingulate cortex, right inferior frontal gyrus, bilateral middle frontal gyrus, bilateral inferior parietal lobe, bilateral insula, bilateral superior temporal gyrus, and right precuneus (Figure 5E). This network was positively correlated with age perception of neutral stimuli among older participants and positive stimuli among younger participants (Figure 5F).

[Insert Figure 5 about here]

Structure-function relationship. We next examined the relationship between anterior and posterior cingulum microstructure and brain activity during the MET, with all three emotional valences, and in both age groups.

Anterior cingulum. Our analyses testing association between FA of the anterior cingulum and brain activation during the affective empathy revealed one significant LV which accounted for 25% of covariance of the data ($p < 0.001$). This LV delineated a pattern of brain activity which was activated during all emotional valence stimuli among older adults. No other effects were reliable (all CIs crossed zero; Figure 6C). In other words, older participants with higher FA values in the anterior cingulum bundle recruited this functional network to a larger extent for all stimuli during the affective empathy task. This network included left superior frontal gyrus, bilateral insula, left superior temporal gyrus, bilateral parietal lobe, left hippocampus, left caudate, and left fusiform gyrus (Figure 6B).

[Insert Figure 6 around here]

Additionally, our analyses with the anterior cingulum and brain activation during cognitive empathy revealed a significant LV which accounted for 25% of covariance of the data ($p = 0.008$). This LV yield a pattern of brain activation which was positively correlated with the negative stimuli among younger adults. No other effects were reliable (CIs crossing zero). In other words, younger participants with higher FA values in the anterior cingulum bundle recruited this functional network to a larger extent for negative stimuli during the cognitive empathy task. This pattern included areas such as superior frontal gyrus, bilateral superior temporal gyrus, posterior and anterior cingulate.

Posterior cingulum. Our results including the posterior cingulum FA tracts during the affective empathy revealed one significant LV which accounted for 28% of covariance of the

data (p = 0.004) whereby increasing FA values in both left and right posterior cingulum were positively correlated with the functional network in older adults during affective empathy for positive stimuli. In other words, older individuals with higher FA values in the posterior cingulum bundle recruited this functional network to a larger extent for positive stimuli during the affective empathy task (Figure 7C). In younger adults, on the other hand, the correlation was only reliable for tract in the right hemisphere. This pattern comprised the ventromedial prefrontal cortex, medial prefrontal cortex, and cuneus (Figure 7B).

Our analyses of the association between FA in the posterior cingulum and the brain activity during the cognitive empathy revealed one LV which accounted for 27% of covariance of the data (p = 0.008). This LV delineated a pattern of brain activity which was positively correlated with the negative stimuli only among younger adults. No other effects were reliable (all CIs crossed zero). In other words, younger participants with higher FA values in the posterior cingulum bundle recruited this functional network to a larger extent for negative stimuli during the cognitive empathy task. This pattern included bilateral middle frontal gyrus, superior frontal gyrus, anterior cingulate, bilateral inferior parietal lobe, right superior temporal gyrus.

[Insert Figure 7 about here]

Uncinate fasciculus. Additional analysis using the uncinate fasciculus FA values and brain activation during the affective empathy revealed a significant LV which accounted for 14% of covariance of the data (p = 0.02). This pattern was positively correlated with all conditions only among older adults. In other words, older adults with higher FA values in the uncinate fasciculus tract recruited this functional network to a larger extent for all conditions relative to younger adults. No effect was reliable among younger adults. This network included anterior cingulate cortex, medial and superior frontal cortex, bilateral insula, posterior cingulate, and right caudate.

Discussion

Cognitive empathy has been consistently shown to decrease with age whereas studies measuring age-related differences in affective empathy have generated mixed findings. Our study went beyond these past approaches and generated several novel insights regarding age-related differences in cognitive and affective empathy both in behavior and in the structural and functional brain networks involved.

Behaviorally, we found that older adults responded more slowly to empathic conditions, than to the age perception condition, and their response time was affected by the valence during cognitive, but not affective, empathy. At the neural level, we did not find any support for an age-related reduced activity for cognitive empathy, not supporting *Hypothesis 1a*. For affective empathy, both age groups, recruited a similar brain network, thus supporting *Hypothesis 1b*. We also found that older, but not younger, participants engaged regions of the salience network in response to negative emotions during cognitive empathy, supporting *Hypothesis 2a*. In contrast, with regards to affective empathy, both age groups, and not only older adults, engaged a similar pattern of brain regions that contained nodes of the default mode network in response to positive emotions, partially supporting our *Hypothesis 2b*. Our structure-function analyses revealed that the microstructure of the posterior, but not the anterior, cingulum bundle was related to the engagement of major nodes of the default mode network during the affective empathy condition with positive stimuli in both age groups.

Age-related differences in cognitive and affective empathy

Neither our brain nor our behavioral data supported age-related differences in affective empathy. Thus, in contrast to Chen and colleagues (2014), we did not observe reduced engagement of core empathy regions including the anterior insula, mid-cingulate, and medial

prefrontal cortex in older participants. Rather, both younger and older adults recruited these regions similarly during the performance of the affective empathy task. Differences in the type of stimuli used in our study (i.e., non-pain stimuli) compared to the pain stimuli used in Chen et al. may underlie these divergent findings. Speaking against this methodological explanation, a recent meta-analysis found similarities in empathic responses to pain and non-pain stimuli (Timmers et al., 2018); this comparability across stimulus types, however, has not been confirmed in research with older individuals yet. Additionally, it has to be noted that Chen and colleagues investigated empathic responses in three age groups; younger, middle age, and older adults and while the neural correlates of each age group were compared, the use of different stimuli and different population sample has to be noted when compared with the results of the current study. Further to this is the use of univariate, contrast-based analyses for the imaging results which is in contrast with the use of the multivariate method in the current study.

Our functional MRI findings for affective empathy do not support the notion of diminished internal bodily perception (interoceptive awareness) among older adults (Mendes, 2010), but functional sparing for affective processing in aging is in line with the brain maintenance hypothesis discussed in the cognitive aging literature (Nyberg et al., 2012). This idea of functional reserve that protects older adults from decline may be particularly apposite to our data given that participants in the current study were cognitively high functioning (see background measures in Table 1). Thus, they may have had a high cognitive reserve, which could have resulted in improved performance, on a level comparable with younger participants, especially with the affective empathy task which may have been easier to perform than the cognitive empathy task. Future research will be able to test this interpretation.

The role of valence on cognitive empathy

Age-related differences were observed in valence modulation during cognitive empathy. While the age groups differed in their responses by the emotional valence behaviorally. On the neural level, however, we found age-related differences in that older compared to younger participants recruited the salience network more in their empathic response to negative stimuli during the cognitive empathy condition. They engaged a neural network that comprised bilateral insula and anterior cingulate, core nodes of the salience network (Menon, 2015; Menon & Uddin, 2010), with cognitive empathy to negative emotions. This finding aligns with behavioral evidence that older compared to younger adults experience greater difficulty processing negative than positive emotions (Hayes et al., 2020; Ruffman et al., 2008). In line with these meta-analyses, processing of negative (relative to positive) emotions may be more effortful and considered more threatening for older adults which was not in line with their goals and implicit motivations. As a result, enhanced prefrontal cortex and insula activation are observed in processing negative vs. positive information among older adults (Ebner et al., 2012; Ziaei et al., 2016) possibly reflective of greater cognitive control and/or emotional down-regulatory processes.

One possibility for engagement of the salience network during cognitive empathy to negative emotions in older adults is that this network, and insula specifically, is involved in orienting attention towards relevant stimuli in the environment (Menon & Uddin, 2010). Given the salience feature of negative emotions and their importance for survival, orienting attention towards negative emotions is crucial and is thus associated with the insular response. Insular activity in this context may be reflective of a response that is commonly expressed among various cognitive tasks to guide behavior in dynamic social contexts (Bernhardt & Singer, 2012),

crucial for recognizing negative emotions. Our result, however, contradicts suggestions of age-related reductions in insular activation subserving interoception and the simulation of emotions in others (Mather, 2016). Further investigation is needed to determine the relationship between bodily response (such as heart rate variability and skin conductance) and insular activity during empathy, and social cognition more broadly, across adulthood.

The role of valence on affective empathy

Our finding of no age-related difference in affective responding to positive stimuli is also largely in line with the socioemotional selectivity theory (SST) (Carstensen et al., 2003; Carstensen et al., 1999) which proposes that older participants preferentially process positive over negative stimuli. In other words, older adults' bias towards positive emotions may have facilitated processing of positive emotions in the affective empathy task, resulting in comparable brain and behavioral activity patterns between the age groups in this condition. Thus, the present study's results suggest that the positivity effect reported in the aging literature for various cognitive and social-cognitive processes also extends to affective empathic responding to positive stimuli. This finding aligns well with the motivational empathy account (Weisz & Zaki, 2018). In fact, older adults might be more motivated to process positive than negative emotions, as these emotions are in line with their social goals. This motivational bias may lead to differential processing of positive vs. negative stimuli with regards to enhanced empathic responding to positive over negative emotions among older adults.

Another explanation for similar responses among both age groups towards positive stimuli during the MET task might be the tendency to show empathic responses towards positive emotions at any age. Considering evidence that it is easier to show support for a partner's positive than negative life events (Andreychik, 2019; Gable et al., 2006), it is possible that both

younger and older adults may have recruited a similar network for empathic responses to positive relative to negative emotions. Recent neuroimaging evidence furthermore supports the idea that positive empathy makes prosocial acts feel more rewarding, activating regions such as the ventromedial prefrontal cortex (Harbaugh et al., 2007; Hare et al., 2010). Thus, empathizing with positive emotions may be more rewarding and/or easier, for both younger and older adults.

All together, our findings reported here well align with previous studies supporting salience network (including the insula and the cingulate cortex) activation during cognitive empathy (Bernhardt & Singer, 2012; Pasquini et al., 2020; Rankin et al., 2006). Although sparse, positive empathy can engage areas related to the positive emotions such as the default mode network as well as the reward system such as the ventral striatum. Thus, the engagement of regions associated with the default mode network for positive emotions during the affective empathy in this experiment is also in line with previous studies (Ziaei et al., 2019; for a review see Morelli et al., 2015). Based on our results, we propose that there might be a distinction in the brain networks recruited by the positive vs. negative emotions, based on the task context and effort required for the task, among the elderly population which needs to be considered in future studies.

Structure-function relationship

We also found involvement of the posterior cingulate cortex during affective empathy for positive emotions in both age groups. In particular, there was a high concordance between regions that were connected by the posterior cingulum and regions that were activated for positive empathy during the MET task in our study. A growing body of work now supports that the default mode network might play a role in the processing of positive emotions, possibly due to lower cognitive processing required for positive stimuli, and greater salient features of these

stimuli (e.g., showing teeth; Ziaei & Fischer, 2016). Additionally, research has previously shown that the regions connected with the cingulum bundle have a high overlap with the default mode network, indicating an association between structural and functional connectivity of the default mode network (van den Heuvel et al., 2008). However, what has not been demonstrated before, and our results speak to this gap, is the role of these areas for affective empathy, especially for positive stimuli in aging. Older adults with higher FA values in the cingulum bundle tract exhibited higher activity in this network for positive emotions. This result again speaks to the motivational account of empathy and provides the first evidence for the association between structure-function in positive empathic responses in aging.

The activation of posterior cingulate with positive affective empathy may reflect self-referential (affective) processing in linking one's own and another's emotional state to enable adequate empathic responding. In support of this interpretation, the posterior cingulate cortex has been shown to play a role in a wide range of social-cognitive processes (Brewer et al., 2013; Sperduti et al., 2012). For example, posterior cingulate activation is involved in theory of mind and mentalizing (Frith & Frith, 2006; Mitchell, 2009; Molenberghs et al., 2016). A meta-analysis furthermore showed that the posterior cingulate cortex subserves empathy (Bzdok et al., 2012a), and specifically the evaluation of how "one relates to one's experience" (Brewer et al. (2013). Our findings importantly add to previous literature by demonstrating a role for the posterior cingulate in affective empathy in older adults. Our findings are in line with the last-in-first-out hypothesis (Madden et al, 2019) that proposes that prefrontal cortex areas, relative to posterior parts of the brain, are the first affected by the aging process. The higher FA values in the posterior cingulum associated with affective empathy as observed in the present study suggest that structural integrity of this region plays a role in the subserving affective empathic response.

Limitations

We acknowledge that we considered reaction time in this study as an indicator for cognitive and affective empathy, whereas, in real life, our empathic responses might not be evaluated with how fast we respond, but how appropriate we respond to the stimuli and how well we can express our empathic concern towards others. Future studies are needed to marry behavioral responses such as response time and other real-life physiological and behavioral measures to study empathic responses. Additionally, future research is needed to investigate more ecological ways to measure empathic responses to emotional stimuli and to investigate the relationship between psychiatric symptoms, such as depression and anxiety, and empathic responses.

Conclusion

This is the first study to distinguish behavioral, structural, and functional responses for an empathic response towards positive vs. negative emotions among younger and older adults. Older (but not young) adults engaged the salience network during cognitive empathy in response to negative emotions, which could reflect older adults' difficulty in the processing of and/or their enhanced interoception for negative emotions during cognitive empathy. Both age groups recruited a bilateral network including nodes of the default mode network, possibly reflecting self-referential processing and/or decreased cognitive effort during affectively empathizing with positive emotions. White matter microstructure of the cingulum bundle, and specifically the posterior subdivision, furthermore, was related to positive affective empathy, suggesting that the microstructural integrity of the posterior cingulum may provide structural support for functional networks involved in affective empathy for positive stimuli. These findings show that valence plays a critical role in empathic response both in younger and older adults and therefore needs to be considered in investigations into higher-order social cognitive functions not only in the field

of gerontology but also in other populations with deficits in social-cognitive function (e.g., individuals with an autism spectrum disorder, neurodegenerative (Henry et al., 2016), or epilepsy disorders (Ziaei et al., 2021). Based on our results future research should test the extent to which emotions displayed by another affect social interactions such as closeness or altruistic behavior as well as general well-being via empathic responses in both younger and older adults.

Data and code availability statement

The preprocessed and analyzed functional data, processed structural data, and experimental task's code of this study are available upon request.

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Figures

Figure 1

Figure 2

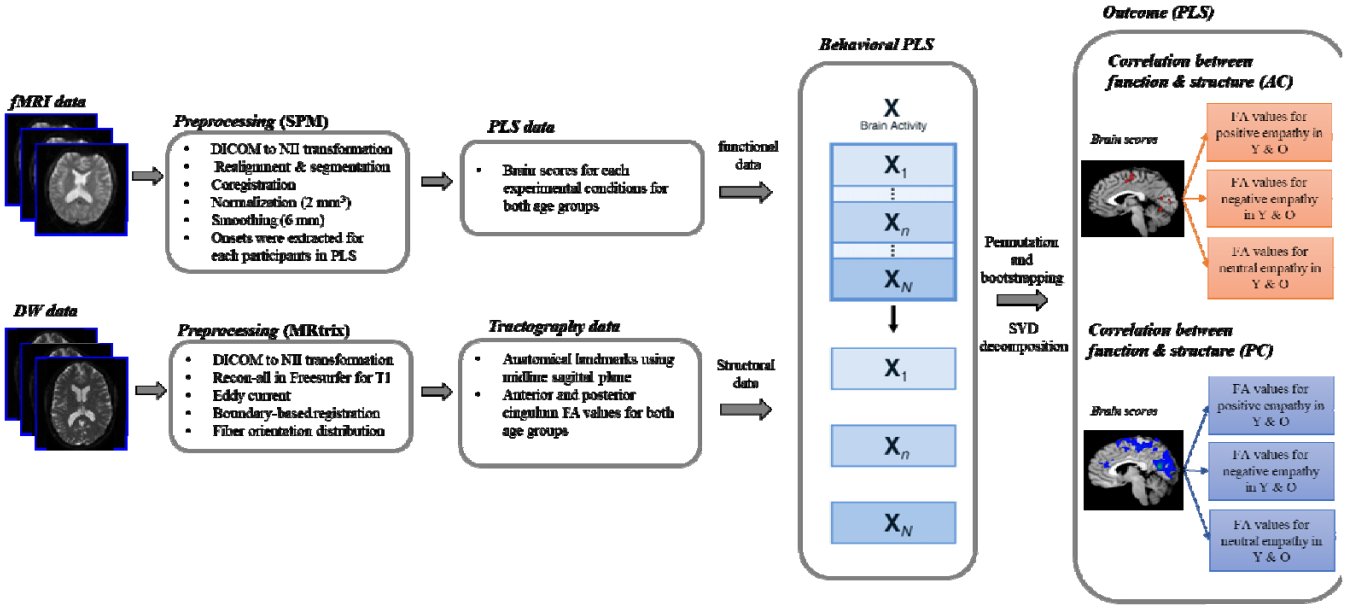

fMRI data
Preprocessing (SPM)
DICOM to NII transformation
Realignment & segmentation
Coregistration
Normalization (2 mm³)
Smoothing (6 mm)
Onsets were extracted for each participants in PLS
PLS data
Brain scores for each experimental conditions for both age groups
functional data
DW data
Preprocessing (MRtrix)
DICOM to NII transformation
Recon-all in Freesurfer for T1
Eddy current
Boundary-based registration
Fiber orientation distribution
Tractography data
Anatomical landmarks using midline sagittal plane
Anterior and posterior cingulum FA values for both age groups
Structural data
Behavioral PLS
X
Brain Activity
X1
Xn
XN
Permutation and bootstrapping
SVD decomposition
Outcome (PLS)
Correlation between function & structure (AC)
Brain scores
FA values for positive empathy in Y & O
FA values for negative empathy in Y & O
FA values for neutral empathy in Y & O
Correlation between function & structure (PC)
Brain scores
FA values for positive empathy in Y & O
FA values for negative empathy in Y & O
FA values for neutral empathy in Y & O

Figure 3

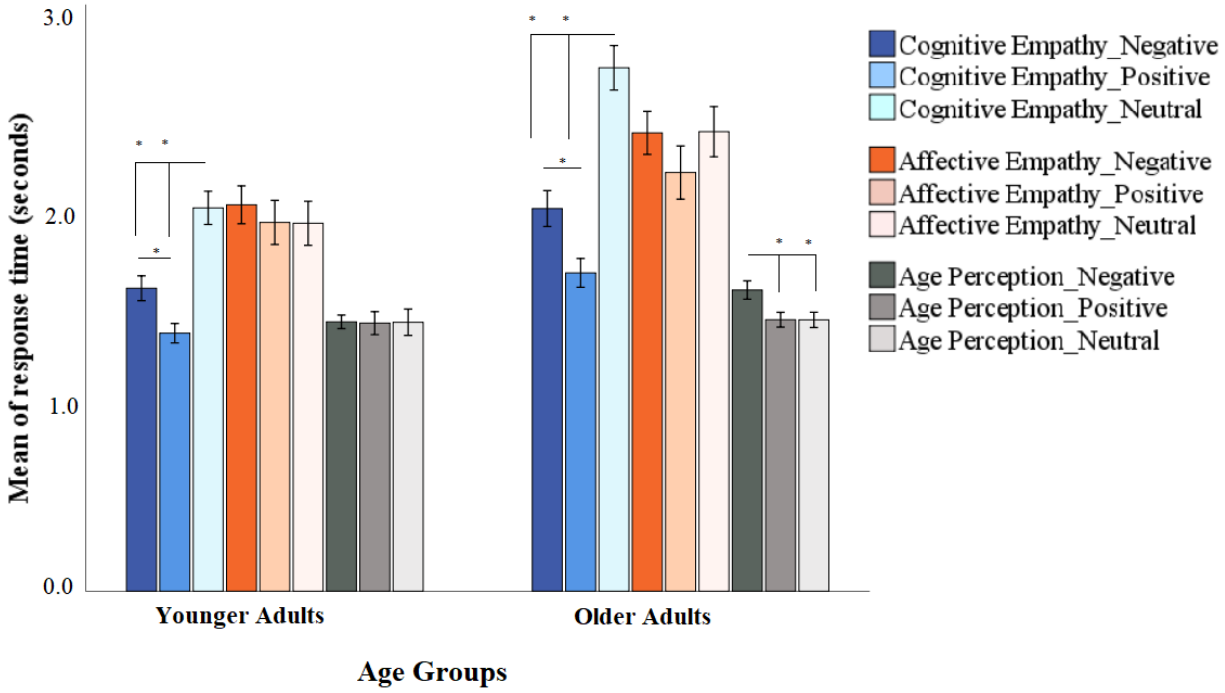

3.0
2.0
1.0
0.0
Mean of response time (seconds)
Younger Adults
Older Adults
Age Groups
Cognitive Empathy_Negative
Cognitive Empathy_Positive
Cognitive Empathy_Neutral
Affective Empathy_Negative
Affective Empathy_Positive
Affective Empathy_Neutral
Age Perception_Negative
Age Perception_Positive
Age Perception_Neutral

Figure 4

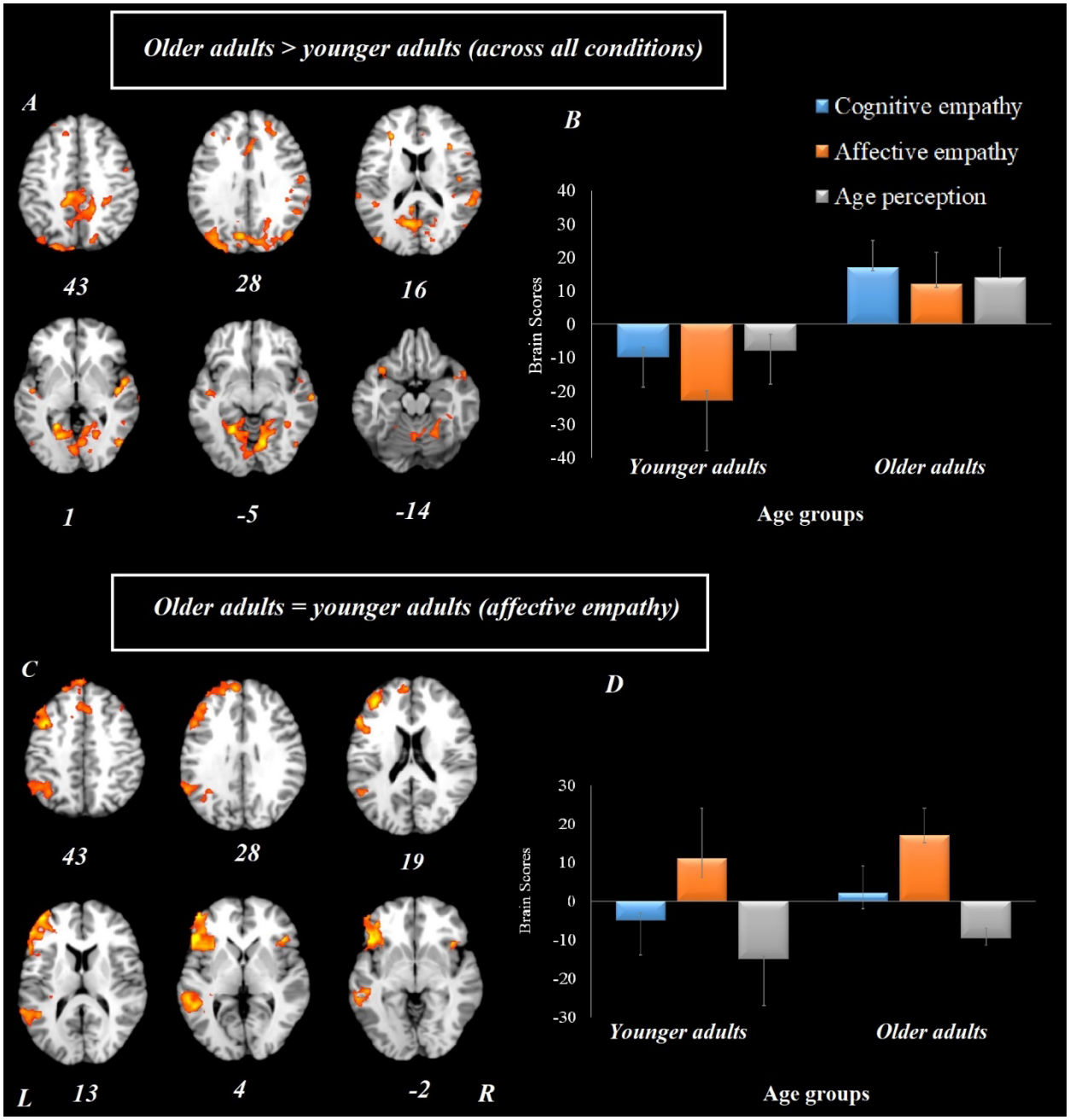

Older adults > younger adults (across all conditions)
A
43
28
16
1
-5
-14
B
Cognitive empathy
Affective empathy
Age perception
Brain Scores
40
30
20
10
0
-10
-20
-30
-40
Younger adults
Older adults
Age groups
Older adults = younger adults (affective empathy)
C
43
28
19
L
13
4
-2
R
D
Brain Scores
30
20
10
0
-10
-20
-30
Younger adults
Older adults
Age groups

Figure 5

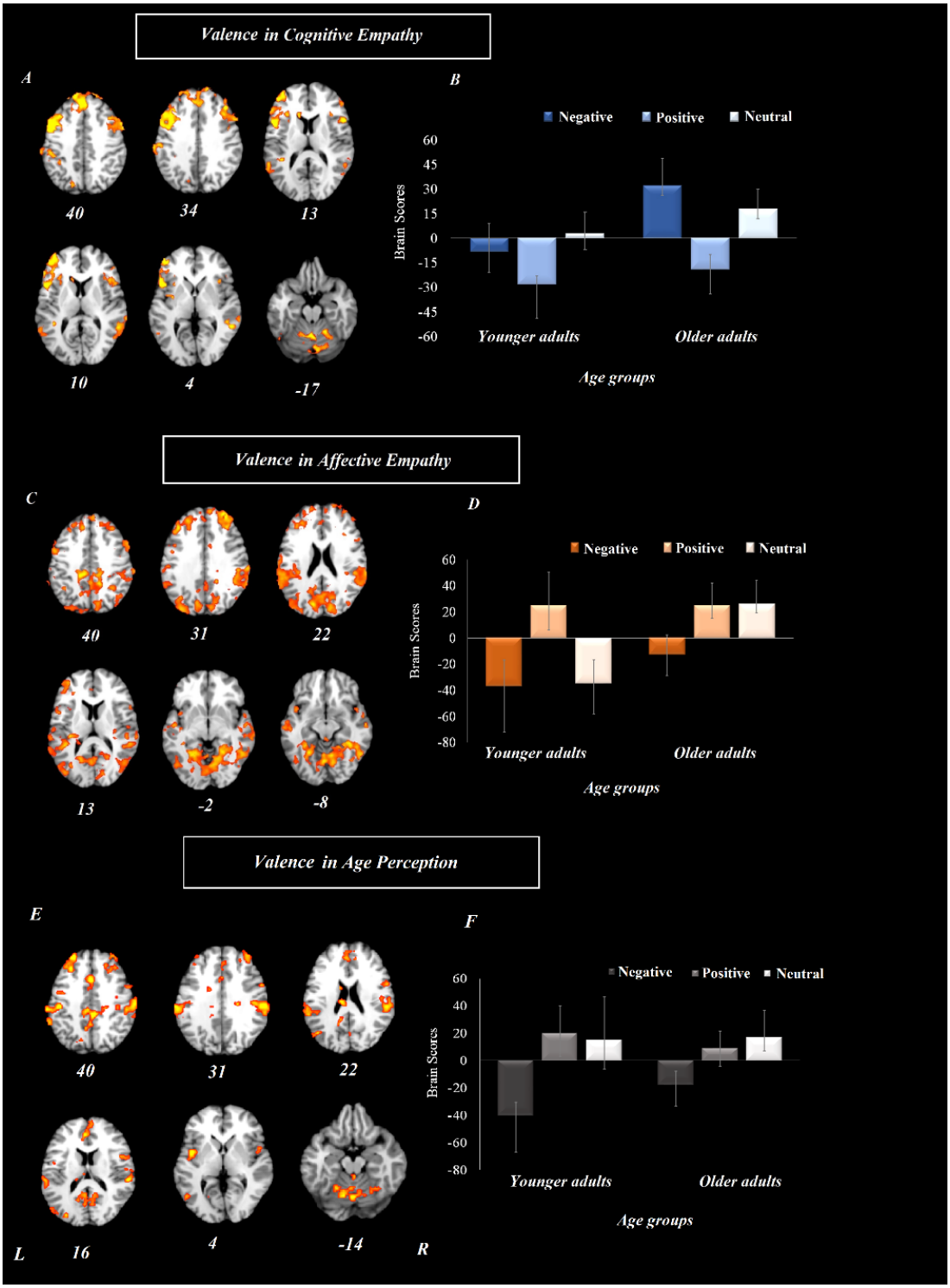

Valence in Cognitive Empathy
A
40
34
13
10
4
-17
B
Negative
Positive
Neutral
Brain Scores
60
45
30
15
0
-15
-30
-45
-60
Younger adults
Older adults
Age groups
Valence in Affective Empathy
C
40
31
22
13
-2
-8
D
Negative
Positive
Neutral
Brain Scores
60
40
20
0
-20
-40
-60
-80
Younger adults
Older adults
Age groups
Valence in Age Perception
E
40
31
22
L
16
4
-14
R
F
Negative
Positive
Neutral
Brain Scores
60
40
20
0
-20
-40
-60
-80
Younger adults
Older adults
Age groups

Figure 6

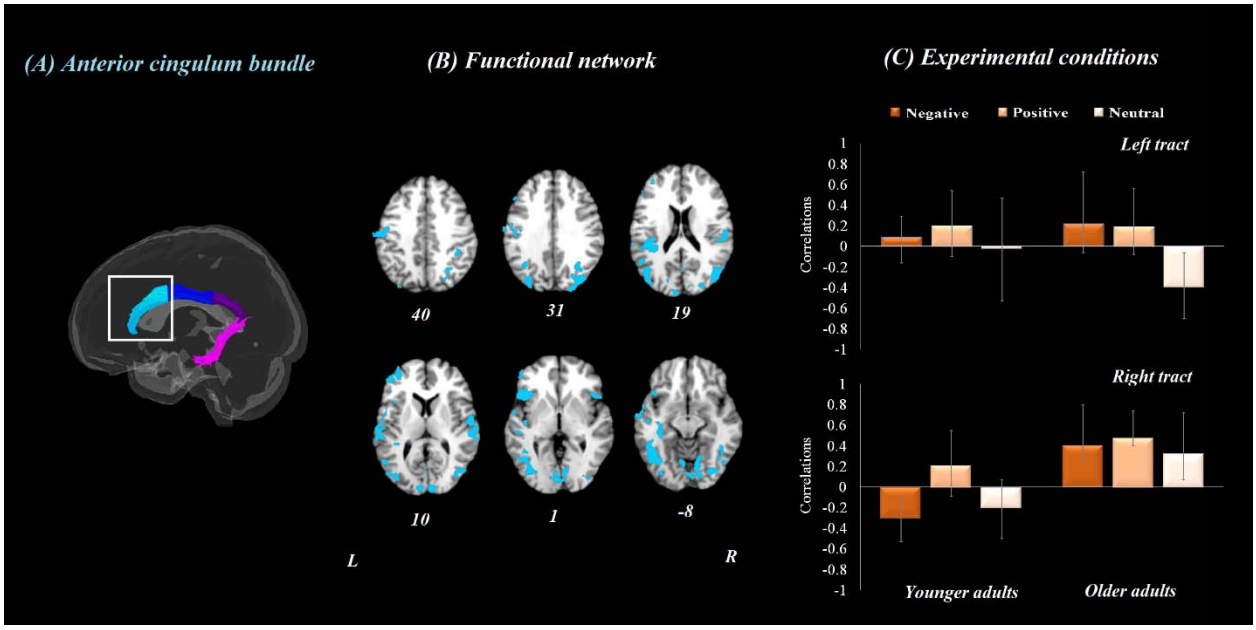
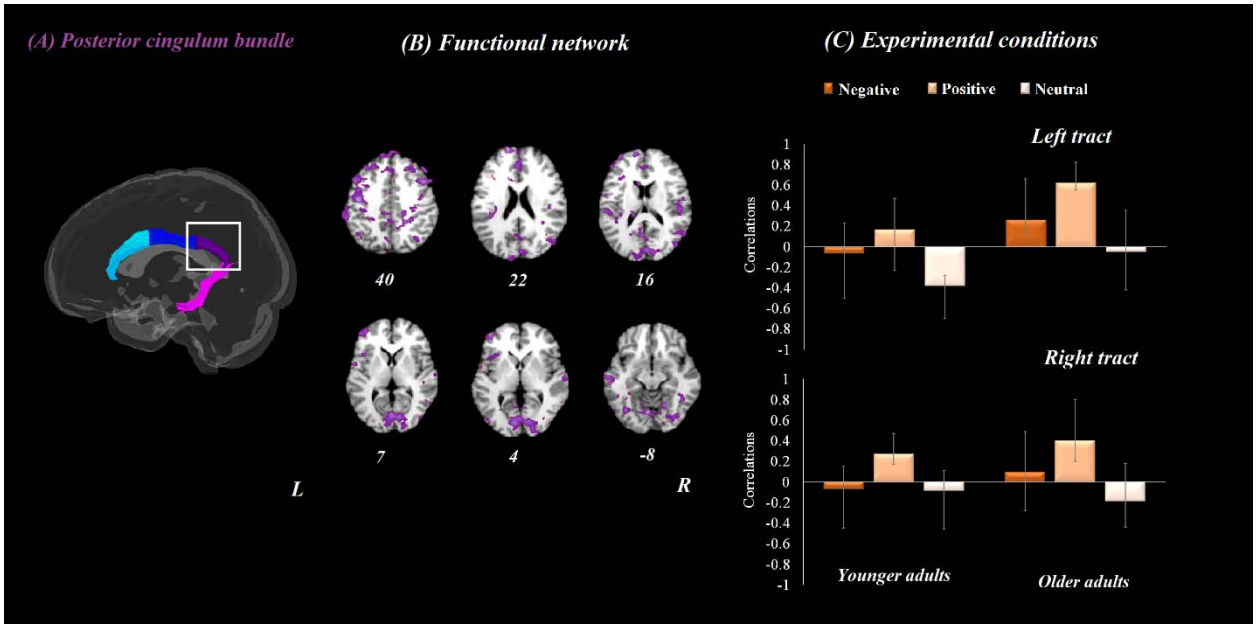


Figure 7



Captions

Figure 1. Experimental task. The task included three experimental conditions: cognitive empathy, affective empathy, and age perception. Each condition consisted of three blocks of either positive, negative, or neutral images. Each condition started with a 3-second instruction, followed by a presentation of 7 images, each for 6 seconds, for a total of 42 seconds per block. Following each block, a jittered fixation cross (duration: 1.5, 2, or 2.5 seconds) was presented.

Figure 2. Methodological approach. Following preprocessing of fMRI and DTI data, cingulum fractional anisotropy (FA) values and brain scores from experimental conditions were entered into the model to delineate latent variables that best describe the relationship between structural and functional data. DICOM = Digital Imaging and Communications in Medicine; NII = NIFTI; SPM = Statistical Parametric Mapping; PLS = Partial Least Square; DW = Diffusion Weighted; MRI = Magnetic Resonance Imaging; Y = Younger Adults; O = Older Adults.

Figure 3. Panel A. Mean response times (in seconds) for the three experimental conditions (cognitive empathy, affective empathy, age perception) in younger and older participants for positive, negative, and neutral stimuli. N = number; Error bars = +/- 1 standard error. * denotes $p < .000$.

Figure 4. Results from the whole-brain analysis for the three experimental conditions (cognitive empathy, affective empathy, age perception) in younger and older participants. Panel A represents the brain activity pattern across all three experimental conditions, differentiating between younger and older participants. Panel B represents brain scores associated with the brain

activity pattern presented in Panel A. Panel C represents the brain activity pattern differentiating affective empathy from the other two experimental conditions, similarly for younger and older participants. Panel D represents brain scores associated with the brain activity pattern presented in Panel C. Error bars represent confidence intervals at 95%. For all reported regions a bootstrap ratio of ≥ 2.5 and cluster size of ≥ 50 voxels was applied. L = left hemisphere, R = right hemisphere.

Figure 5. Results from the whole-brain analysis regarding valence modulation (positive, negative, neutral) for cognitive empathy, affective empathy, and age perception in younger and older participants. Panel A refers to cognitive empathy and represents the brain activity pattern differentiating negative and neutral from positive stimuli in older participants. Panel B represents brain scores associated with the brain activity pattern presented in Panel A. Panel C refers to affective empathy and represents the brain activity pattern differentiating positive from negative and neutral stimuli in younger participants and positive and neutral from negative stimuli in older participants. Panel D represents brain scores associated with the brain activity pattern presented in Panel C. Panel E refers to age perception and represents the brain activity pattern differentiating positive from negative and neutral stimuli in younger participants and neutral from positive and negative stimuli in older participants. Panel F represents brain scores associated with the brain activity pattern presented in Panel E. Error bars represent confidence intervals at 95%. For all reported regions a bootstrap ratio of ≥ 2.5 and cluster size of ≥ 50 voxels was applied. L = left hemisphere, R = right hemisphere.

Figure 6. Results from whole-brain analyses and anterior cingulum FA values in both age groups during affective empathy condition. Panel A refers to the cingulum bundle tract. Panel B refers to the brain activation pattern which was correlated with the FA values of the anterior cingulum bundle during the experimental conditions. Panel C refers to the correlation between FA values and brain patterns for each experimental condition in each age group. Error bars represent confidence intervals at 95%. For all reported regions a bootstrap ratio of ≥ 2.5 and cluster size of ≥ 50 voxels was applied. L = left hemisphere, R = right hemisphere.

Figure 7. Results from whole-brain analyses and posterior cingulum FA values in both age groups during affective empathy condition. Panel A refers to the cingulum bundle tract. Panel B refers to the brain activation pattern which was correlated with the FA values of the posterior cingulum bundle during the experimental conditions. Panel C refers to the correlation between FA values and brain patterns for each experimental condition in each age group. Error bars represent confidence intervals at 95%. For all reported regions a bootstrap ratio of ≥ 2.5 and cluster size of ≥ 50 voxels was applied. L = left hemisphere, R = right hemisphere.

Tables

Table 1. Descriptive data (means and standard deviations) and inferential statistics for background measures in younger and older participants

	Younger Participants		Older Participants		Age-Group Differences	
	M	*SD*	*M*	*SD*	*t*	*df*
Demographics						
Age (years)	21.72	3.81	71.52	3.80	46.19**	48
Gender	13 females		14 females			
Education (years)	15.50	2.46	17.34	8.79	1.01	48
Executive Functioning						
Verbal Fluency Test	47.84	10.67	53.20	12.42	1.63	48
Stroop Interference Score	0.23	0.25	0.29	0.18	0.82	48
Task Switching Index	20.63	9.02	24.86	11.99	1.35	45
Raven IQ	6.40	1.77	5.68	1.97	1.35	48
Emotional Well-Being						
DASS-21						

Stress	6.40	6.05	1.33	2.33	3.83**	47
Anxiety	5.12	3.60	1.00	1.56	5.14**	47
Depression	10.40	5.94	3.66	3.85	4.68**	47
Empathy						
IRI						
Fantasy	16.12	4.70	13.64	5.42	1.72	48
Empathic concern	17.88	3.63	18.68	3.55	0.78	48
Perspective taking	19.44	4.11	19.64	3.46	0.18	48
Personal distress	12.04	5.67	8.64	4.31	2.38*	48
Empathy Quotient	44.44	11.16	49.08	11.45	1.45	48
RMET	25.76	4.20	27.72	4.37	1.61	48

Note. * $p < 0.05$, ** $p < .001$. Verbal Fluency Test (Benton & Hamsher, 1976): total number of words for letters F, A, and S; Stroop Interference Score (Ziaei et al., 2015) = ((response time in incongruent trials – response time in neutral trials)/response time in neutral trials); Task-Switching Index (Reitan & Wolfson, 1986): Trail Making Test Part B – Trail Making Test Part A; Raven IQ (Kirchner, 1958) = total number of correct responses; DASS-21 = Depression Anxiety Stress Scale (Lovibond & Lovibond, 1995); IRI = Interpersonal Reactivity Index (Davis, 1983); RMET = Reading the Mind in the Eye Test (Baron-Cohen et al., 2001); *df* = degree of freedom; *SD* = standard deviation; *M* = mean; *t* = student t-test.

Table 2. Whole-brain results showing pattern of activity across younger and older participants in positive and negative emotional valence conditions

Regions	Hem	MNI coordinates	BSR
		X Y Z	
Age-related differences in valence modulation during cognitive empathy			
Older participants > younger participants (negative stimuli)			
Middle frontal gyrus	L	-37 52 11	-4.71
Inferior frontal gyrus	L	-49 14 11	-5.42
	R	52 18 11	-3.75
Insula	L	-44 16 7	-4.19
	R	37 20 7	-3.01
Medial frontal gyrus	R	0 51 28	-3.53
Superior frontal gyrus	L	-3 46 42	-4.54
Inferior parietal lobe	L	-46 -28 50	-4.15
Superior temporal gyrus	R	56 -46 11	-3.73
	L	-58 -48 11	-3.40
Caudate	L	-11 13 20	-4.16
Age-related similarity in valence modulation during affective empathy			

Older participants = younger participants (positive stimuli)			
Anterior cingulate gyrus	L	-4 38 16	4.43
Middle frontal gyrus	L	-24 42 32	4.40
Inferior frontal gyrus	L	-50 6 16	4.79
Superior frontal gyrus	R	30 52 32	5.82
Insula	L	-36 -31 20	5.00
	R	63 -30 20	4.39
Inferior parietal lobe	R	62 -24 32	4.42
Posterior cingulate	R	2 -63 20	4.45
Superior temporal gyrus	L	-38 -36 16	4.81
	R	52 -42 20	3.62
Parahippocampus	R	28 -44 -2	3.74

Note. Hem = hemisphere; L = left, R = right; BSR = bootstrap ratio; MNI = Montreal Neurological Institute. Brain regions with BSR > 3.5 are reported here.