Brain networks involved in empathy for positive and negative emotions in younger and older adults

Abbreviated title: Empathy and aging

Maryam Ziaei[1*], David C. Reutens[1#] & Natalie C. Ebner[2,3,4 #]

[1] Centre for Advanced Imaging, the University of Queensland, Brisbane, Australia

[2] Department of Psychology, University of Florida, Florida, USA

[3] Department of Aging and Geriatric Research, Institute on Aging, University of Florida, Florida, USA

[4] Center for Cognitive Aging and Memory, Department of Clinical and Health Psychology, University of Florida, Gainesville, FL, USA

*Corresponding Author: Maryam Ziaei; Centre for Advanced Imaging, The University of Queensland, St. Lucia, QLD 4072, Australia; Email: maryamziae@gmail.com and maryam.ziaei@cai.uq.edu.au; Tel: +61- 422 916 362

# denotes joint senior authorship

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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. Not well understood yet are the neural correlates underlying cognitive and affective empathy and the extent to which valence modulates these components of empathy in aging. 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, while brain images were acquired in the MRI scanner. Multivariate analysis showed that regions of the salience network, including anterior insula and anterior cingulate, were more involved in cognitive empathy to negative emotions, in older than in younger participants. For affective empathy to positive emotions, in contrast, younger and older participants recruited a similar brain network including the main nodes of the default mode network. These results provide novel insights into the neural networks subserving cognitive and affective empathy in younger and older adults and highlight a modulatory role of valence on empathy in aging. Our findings highlight the importance of valence for the study of higher-order social-cognitive processes such as empathy in aging.

Keywords: empathy, aging, salience network, default network, PLS, multivariate

Introduction

Empathic response is a social-cognitive capacity and refers to the understanding of and response to others' unique experience of emotions (Decety et al., 2006). Empathy contributes to successful social interaction and enhances prosociality and positive health outcomes (Beadle et al., 2019; Sun et al., 2019). The literature often distinguishes between two components of empathy: *cognitive* empathy, the ability to decode and understand another's perspective, and *affective* empathy, the affective sharing of another's emotional states (Singer et al., 2009).

Empathy in aging

Mounting evidence suggests age-related decline in social-cognitive capacities including perception of eye gaze (Slessor et al., 2010; Ziaei et al., 2016), emotional facial expression (Ruffman et al., 2008), theory of mind (Henry et al., 2013), and social behavior (von Hippel et al., 2005). 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). Taken together, these previous studies largely agree that aging is associated with decline in cognitive empathy (Beadle et al., 2019; Henry et al., 2013). Evidence is less clear for affective empathy for which some studies suggest no age-related differences (Bailey et al., 2008; Beadle et al., 2012) and other studies support an increase in affective empathy with age (Grühn et al., 2008; O'Brien et al., 2012).

Even more sparse are studies measuring state empathy 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 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 a note by cancer patients describing their experiences with the disease.

Thus, the current research consistently suggests that cognitive empathy is lower in older than in younger adults. Observed age effects on affective empathy, however, are more mixed with some studies reporting age-related increase, others age-related decrease, and yet others no differences in affective empathy between the age groups. Also, not yet well understood are the age-related differences in neural substrates subserving cognitive and affective empathy using non-pain stimuli.

Neural correlates of empathy

Anterior insula, mid and dorsal anterior cingulate gyrus, and temporo-parietal junction have been identified as key areas involved in empathy (Bernhardt et al., 2012; Bzdok et al., 2012b; Decety et al., 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 an age-related decrease in activation of insula and anterior cingulate during this task. Of note, while recent meta-analytic evidence supports similarities in the neural correlates of empathy in response to pain relative to non-pain stimuli (Timmers et al., 2018), processing of empathy to non-pain stimuli has not been studied in older adults, and will be addressed in the present study.

The second study that explored neural substrates underlying empathy in younger and older adults measured both self-reported cognitive and affective empathy and correlated those measures with brain activity during cognitive and affective tasks (e.g., the N-back and a facial affect matching task; (Moore et al., 2015). Using a region of interest analysis, they found that higher levels of affective empathy were associated with deactivation of insula and amygdala during the performance of an N-back working memory task. Of note, Moore and colleagues measured empathic response outside the MRI scanner, and thus their study cannot speak directly to age-related differences in the neural substrates subserving cognitive and affective empathy, as specifically targeted in the present study. Also, given that empathy is a complex and multidimensional process, it is likely that empathic response activates large-scale brain networks and not just individual circumscribed regions as examined in previous studies. To fill this research gap, the present study adopted a multivariate analysis approach that allowed delineation of neural networks underlying cognitive and affective empathy among younger and older adults.

Impact of valence on empathic response in aging

Robust evidence supports that emotional information has prioritized access to further processing over neutral information. This phenomenon is termed ‘emotional enhancement’ and affects cognitive processes such as memory and attention, generally and also specifically in aging (Charles et al., 2003; Leigland et al., 2004; Mather et al., 2003). Further qualifying the emotional enhancement effect, both neuroimaging and behavioural studies over the last two decades have reliably documented that older compared to younger adults show enhanced processing of positive over negative information, such as reflected in greater attention to, and memory for, positive over negative stimuli, termed the “positivity effect” in aging (Mather et al., 2003; Reed et al., 2012; Ziaei et al., 2016b; Ziaei et al., 2015).

While the phenomena of emotional enhancement and the positivity effect in aging have been extensively studied in the context of facial cue processing, there has been no investigation to date of the impact of valence on empathic response in aging. Evidence in younger adults supports the distinction of empathic response to positive vs. negative stimuli, known as positive vs. negative empathy (Morelli et al., 2015). Personal motives critically influence the way people empathize and connect with others (Weisz et al., 2018). People use emotion expressions expressed by others as social signal to interpret what the other person is feeling (Van Kleef, 2009). Therefore, it is plausible that the valence of stimuli (e.g., another's facial expression) impacts empathic response. Given robust support for an age-related shift in motivations away from negative and towards positive emotions, it is reasonable to assume that older adults' empathic responses are impacted by the valence of stimuli. However, the role of valence on empathic response in aging has not been investigated to date and a more nuanced understanding of valence effects on cognitive and affective empathy is warranted.

Current study

This study examined age-related differences in cognitive and affective empathy both on the level of behavior and its underlying neural substrates. The study furthermore addressed the role of valence on cognitive and affective empathic networks both in younger and older adults. We administered a modified version of the Multifaceted Empathy Test (MET) (Dziobek et al., 2011) that measured both cognitive and affective empathy. Following Mazza et al. (2015), we presented positive, negative, and neutral face images to allow for a systematic investigation of the effects of valence on empathic response. We added an age perception condition to allow for a non-empathy control condition.

Predictions regarding age-related differences in cognitive and affective empathy. Based on previous studies (see Beadle & de la Vega, 2019), we predicted that older compared to younger participants would perform more poorly (reflected in longer response times) in cognitive empathy than affective empathy.

Given our hypothesis that older participants will perform more poorly in cognitive empathy than younger participants, we predict that regions such as the amygdala and the limbic system, temporoparietal junction, as well as frontal areas (Yu et al., 2018), known to be involved in processing emotions, will be less engaged by older than younger participants during cognitive empathy.

In contrast, based on previous findings about age-related differences in affective empathy (Beadle et al., 2019), we expected that older participants will perform comparably to or even better than younger participants in the affective empathy condition (as reflected in equal or faster response time). However, given limited evidence on brain responses during affective empathy for non-pain stimuli, we entertained two alternative hypotheses. In particular, given individual differences in brain changes with age, it is possible that brain integrity is preserved in some older adults, resulting in no age-related differences in neural processing during affective empathy. Alternatively, we might observe age-related difference during affective empathy reflected in enhanced activity of core empathic brain areas, such as insula and anterior cingulate cortex (Engen et al., 2013). Thus, we have expectations for age-related differences in neural response during cognitive vs. affective empathy: for cognitive empathy, poorer behavioral performance and reduced activity in emotion perception network, such as amygdala and temporoparietal junction, is expected for older relative to younger participants (*Hypothesis 1a*). For affective empathy, in contrast, we expect equal or enhanced behavioral performance for older compared to

younger participants, which will be reflected in equal or increased empathic network activity, including insula, anterior cingulate cortex, and medial prefrontal cortex (*Hypothesis 1b*).

Predictions regarding age-related differences in valence modulation on cognitive and affective empathy. Based on robust evidence of a positivity effect in aging (Reed et al., 2014), we expected that older participants would be better or at least as good (reflected in equal or faster response times) as younger participants in recognizing positive emotions. For cognitive empathy specifically, we predicted reduced cognitive effort for positive emotions among older participants relative to younger adults, reflected in reduced engagement of regions such as posterior cingulate and ventromedial prefrontal cortex, hubs of the default mode network (Buckner et al., 2008). In contrast, we expected additional cognitive effort for empathic response to negative stimuli among older participants, compared to younger counterparts, which would be reflected in enhanced activity of the salience network, including the insula and anterior cingulate (*Hypothesis 2a*).

Of note, however, current understanding of the neural processes involved in the affective empathy, is limited. Nevertheless, based on this related literature, common regions that are engaged by both positive and negative stimuli are the medial and dorsomedial prefrontal cortex (Morelli et al., 2015). We also expect reduced engagement of areas such as insula and anterior cingulate cortex specifically for negative empathy among older compared to younger adults. In contrast, recognition of positive emotions demands relatively less resources from older adults and, thus, they are more likely to express affective empathy for positive emotions, as reflected in equal or in greater engagement of the ventromedial prefrontal cortex, in older compared to younger participants (*Hypothesis 2b*) (see Figure 1 for summary of hypotheses and predictions).

[Insert Figure 1 about here]

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 24 younger (*M* = 21.81, *SD* = 4.06) and 25 older (*M* = 71.52, *SD* = 3.80) 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. This study was approved by the Queensland University Ethics committee.

All participants were right-handed, English speakers who had normal or corrected-to-normal vision using MRI compatible glasses, and no history of psychiatric illnesses, cardiovascular disease, head or 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 2, the MET consists of naturalistic face images for which participants were asked to indicate (i) what kind of emotion the depicted person feels (cognitive empathy condition), (ii) how strong the emotion is that they (the participants) feel about the depicted person (affective empathy condition), and (iii) how old the depicted person is (age perception control condition). Following Mazza et al. (2015), positive (happy), negative (sad, angry), or neutral face images were presented in each condition and, different from the original Dziobek et al. (2011) design, we used a block design and included three response options. Each block included seven pictures of the same valence, with each image presented for six seconds, for a total duration of 42 seconds per block. While block length in Mazza et al. (2015) was 70 seconds, we shortened it to 42 sec, to improve 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 list of pictures used from each valence category is presented in the supplementary material and valence and arousal ratings are 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). Equal numbers of male and female faces were used across all conditions. Stimuli were presented in color and standardized in size to 507 x 635 pixels, against a gray background.

The task comprised three conditions: a cognitive empathy, an affective empathy, and an age perception control condition. 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 rate “how strong is the emotion you feel about this person?” by choosing “low”, “average”, and “high”. 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.

The task was presented in three runs, each including three blocks (one block for each cognitive empathy, affective empathy, and age perception condition) of positive, negative, and neutral face images, resulting in nine blocks in each run. The order of conditions in each run was pseudo-randomized. To control for the nature of the pictures, stimuli from each valence category were counterbalanced across conditions and runs. That is, 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 recording of responses.

[Insert Figure 2 about here]

Background measures

In the behavioral/neuropsychological test session, participants completed a series of tasks pertaining to executive functioning: the Stroop Task (Jensen et al., 1966), the abbreviated version of the Raven's Progressive Matrices (Bilker et al., 2012), the Trail Making Test (Reitan et al., 1986), and a verbal fluency measure (Newcombe, 1969). Emotional well-being was measured with the Depression, Anxiety, Stress Scale – DASS-21 (Lovibond et al., 1995). In addition, the Empathy Quotient (Baron-Cohen et al., 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. Table 1 provides descriptive data and inference statistics of these measures. 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 subscales of the DASS-21, 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 (all $p < 0.001$).[1]

fMRI image acquisition

Functional images were acquired at the Centre for Advanced Imaging on a 3T Siemens 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 = 52º, multi-band acceleration factor = 5). High-

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

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). 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 and code availability statement

The raw data, results and code of this study are available upon request

Data Analysis

fMRI

Preprocessing. For functional analysis, T2*-weighted images were preprocessed with Statistical Parametric Mapping Software (SPM12; http://www.fil.ion.ucl.ac.uk/spm) implemented in MATLAB 2015b (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 voxel size of 2 mm^3, 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 2012b (The MathWorks Inc., MA), to determine (i) age-related differences in whole-brain activity patterns for the three experimental conditions (cognitive empathy, affective empathy, and age perception); and (ii) age-related differences in modulation of valence (positive, negative, neutral) on the MET task conditions. Of note, our aim in this paper was to identify the interaction between valence and age within each of the three experimental condition. Given differences in neural substrates

underlying cognitive and affective empathy (Yu et al., 2018), we investigated the impact of valence on the neural networks subserving affective vs. cognitive empathy separately.

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. This approach 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 experimental conditions or assumptions about 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 represents linear combinations of the original variables.

Each LV 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. Each LV consists of a spatiotemporal pattern of brain activity (referred to as voxel saliences), a set of weights that indicates the relationship between experimental conditions with brain activity (referred to as task saliences), and the amount of covariance accounted by the LV (referred to as singular value). 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 et al.,

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 *Hypothesis 1*, to determine age-related differences in brain activity patterns for cognitive and affective empathy, we included all three experimental conditions, irrespective of valence, and both age groups. For *Hypothesis 2*, to examine the modulatory role of valence within each experimental condition, we conducted three separate analyses for each of the three experimental conditions, with positive, negative, and neutral valence and both age groups included in each analysis.

Behavioral data

We conducted a repeated measure analysis (ANOVA) on mean response times with the 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 experiment, 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 not considered in the analyses.

Results

Behavioral performance

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. 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. The main

effect for age group ($F(1,48) = 13.15$, $p = 0.003$, $\eta_p^2 = 0.21$) showed that overall older participants responded more slowly than younger participants.

Qualifying these main effects, the following interactions were significant: the experimental condition by age group interaction ($F(2,96) = 8.36$, $p < 0.001$, $\eta_p^2 = 0.14$), in that older compared to younger participants responded more slowly during both empathy conditions, and particularly during cognitive empathy, but not in the age perception control condition; the valence by age group interaction ($F(2,96) = 4.34$, $p = 0.016$, $\eta_p^2 = 0.08$), in that older compared to younger participants responded more slowly to negative than to positive stimuli; the experimental condition by valence interaction ($F(4,192) = 36.53$, $p < 0.001$, $\eta_p^2 = 0.43$), in that participants responded more slowly to neutral than to emotional stimuli during cognitive empathy but not during the other conditions.

Finally the three-way interaction between experimental condition, age group, and valence was significant ($F(4,192) = 2.48$, $p = 0.04$, $\eta_p^2 = 0.05$). As summarized in Figure 3, both younger and older participants responded slower to neutral than to both positive and negative stimuli in the cognitive empathy condition; this difference between the three emotions was not significant for either of the age groups in the affective empathy condition. Also, for younger participants responses to positive, negative, and neutral stimuli were similar in the age perception condition whereas older participants responded faster to positive and neutral relative to negative stimuli in that condition.

[Insert Figure 3 about here]

Whole-brain activity pattern

Age-related differences in cognitive and affective empathy (Hypothesis 1a&1b). 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 only active among older participants but similarly so during 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). This network was recruited by both younger and older participants during affective empathy (Figure 4D), confirming our *hypothesis 1b*. Additionally, this LV included another pattern which corresponded to the age perception control condition in both age groups and included right pre and post central gyrus, bilateral inferior parietal lobe, and right precuneus.

Taken together, the age groups differed in that older, but not younger, participants engaged a brain pattern including anterior, posterior cingulate and temporal areas comparably during all conditions. However, both age groups similarly engaged a left-lateralized network during affective empathy. Thus, in contrast to our prediction (*Hypothesis 1a*), we did not find support for age-related decline in cognitive empathy. However, in support with *Hypothesis 1b*, we found

evidence for comparable neural activation for affective empathy in younger and older participants[2].

[Insert Figure 4 about here]

Age-related differences on the role of valence on cognitive and affective empathy (Hypothesis 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 recruited only by older participants during cognitive empathy to negative and neutral stimuli (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 activated during affective empathy to positive stimuli in both younger and older participants, and 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 recruited by older participants during neutral stimuli and by younger participants during positive stimuli (Figure 5F).

[2] Additional analyses were conducted with reaction times within the whole-brain analyses. The results revealed no reliable effects with reaction times, suggesting that the reported effects here do not reflect purely differences in task difficulty or processing speed.

[Insert Figure 5 about here]

Taken together, during cognitive empathy, older, but not younger, participants engaged a pattern of brain regions resembling the salience network in response to negative and neutral stimuli, not supporting *Hypothesis 2a*. During affective empathy, in contrast, both age groups were similar in recruiting major nodes of the default mode network in response to positive stimuli, suporting *Hypothesis 2b*.

Discussion

Cognitive empathy has been consistently shown to decrease with age whereas studies measuring age-related differences in affective empathy have generated mixed findings. Only two previous studies have investigated the neural correlates of empathic response in older adults and either used only pain stimuli (Chen et al., 2014) or measured self-reported empathic response outside the scanner (Moore et al., 2015). 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 brain, advancing understanding of the neural networks involved in empathic response in adulthood. Furthermore, our study allowed a systematic test of valence modulation of cognitive and affective empathy in younger and older adults.

Behaviorally, we found that older adults responded more slowly to empathic conditions, than age perception condition, and their response time was modulated by the valence during cognitive, but not affective, empathy. At neural level, we did not find any support for age-related reduced activity for cognitive empathy, not supporting our *hypothesis 1a.* For the affective empathy, both age groups, recruited a similar brain network, thus supporting *Hypothesis 1b*. We also found that older, but not younger participants, recruited regions of the salience network with cognitive empathy in response to negative emotions, not in line with our prediction of increased

activity among younger adults in this network in *Hypothesis 2a*. In contrast, with affective empathy in response to positive emotions, both age groups, and not only older adults, recruited a similar pattern of brain regions that contained nodes of the default mode network, supporting our *Hypothesis 2b*. We next discuss the central findings.

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 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. It is possible that 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. 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.

Our brain 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 could offer an explanation, 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 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 were different by the emotional valence behaviroally. On the brain level, however, we found age-related differences in that older compared to younger participants recruited the saliecne network more in their empathic response to negative stimuli during the cognitive empathy condition. They engaged a neural network that comprised bilateral insula, inferior frontal gyrus, and anterior cingulate, core nodes of the salience network (Menon, 2015; Menon et al., 2010), with cognitive empathy to negative emotions. This finding aligns with behavioral evidence that older compared to younger adults experience greater difficulty with processing negative emotions than with positive emotions (Hayes et al., 2020; Ruffman et al., 2008). Our findings also corroborate evidence of increased prefrontal cortex and insula activity for negative emotions in older adults, possibly reflecting more processing effort for and/or greater salient response when processing negative compared to positive stimuli with advanced age (Ebner et al., 2012; Ziaei et al., 2016a).

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 et al., 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 et al., 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 emotions. This finding aligns well with the *motivated empathy account* (Weisz et al., 2018). In fact, older adults might be more motivated to process positive than negative emotions. This motivational bias may lead to differential processing of positive vs. negative stimuli including with regards to empathic responding; and interpretation that will be interesting to follow up on in future studies.

Our finding that valence modulates empathy is largely in line with Morelli and colleagues' (2015) suggestion that empathy is not a uni-dimensional construct and that empathic response to positive emotions is a different construct to general positivity or general empathy for others. Differentiating these diverse constructs and determining the respective brain processes involved

across adulthood will be an interesting future direction to pursue. Also, in the present study we did not measure prosocial behavior and therefore cannot determine the link between empathic responding to positive and negative emotions and prosociality. This research is particularly promising to explore among older adults moving forward given growing evidence of a relationship between empathic response to positive emotions and increased prosocial behavior, social closeness, and well-being among younger adults (Morelli et al., 2015). However, we only found support for the positivity effect in affective empathy, which warrants further investigation.

We also found involvement of the posterior cingulate cortex during affective empathy for positive emotions in both age groups. This involvement of posterior cingulate during empathizing with people who express positive emotions may reflect the relatively lower effort needed with this task. However, it is also possible that the observed posterior cingulate cortex activity with positive affective empathy reflects self-referential (affective) processing in linking one's own and another's emotional state to enable adequate empathic responding. In support of this interpretation, 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 et al., 2006; Mitchell, 2009; Molenberghs et al., 2016). A meta-analysis furthermore showed that 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. It has to be noted that one of the limitation of this study is the use of block design, in which multiple pictures of the same valence was presented within a block. This design feature could have biased response times during the task. While the block design allowed us to obtain a better

brain signal, presentation of pictures with the same valence within a block may have led to valence habituation effects. Further investigation is needed to partial this out from the observed effect.

Conclusion

This is the first study to distinguish behavioral and brain responses for 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. Furthermore, 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. 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 autism spectrum disorder or neurodegenerative disorders; Henry et al., 2016). 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.

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Figures

Figure 1

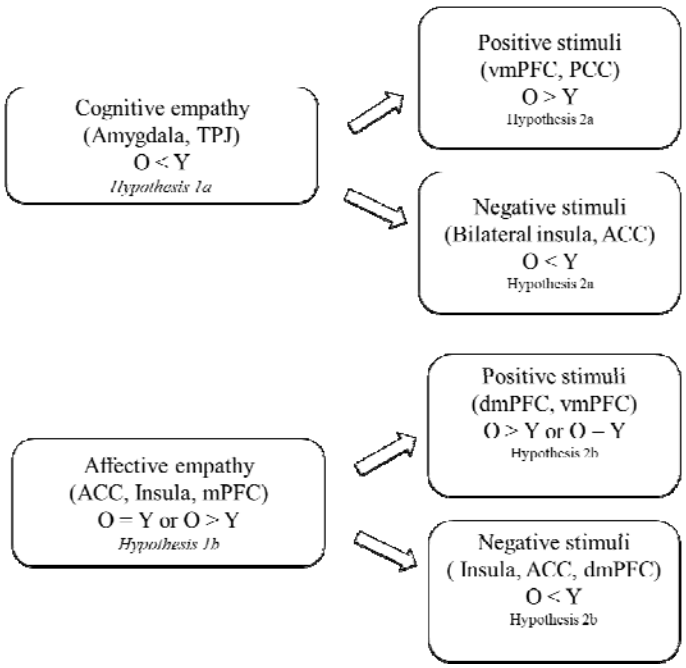


Figure 2

Instruction
(3 sec)
Positive block
7 pictures
(42 sec)
Jittered
fixation cross
(1.5, 2, 2.5 sec)
Negative block
7 pictures
(42 sec)
Jittered
fixation cross
(1.5, 2, 2.5 sec)
Neutral block
7 pictures
(42 sec)
Jittered
fixation cross
(1.5, 2, 2.5 sec)
Cognitive Empathy
What kind of emotion does this person feel?
positive negative neutral
+
positive negative neutral
+
positive negative neutral
+
Affective Empathy
How strong is the emotion you feel about this person?
weak average strong
+
weak average strong
+
weak average strong
+
Age Perception
What is the age of this person?
child adult elderly
+
child adult elderly
+
child adult elderly
+

Figure 3

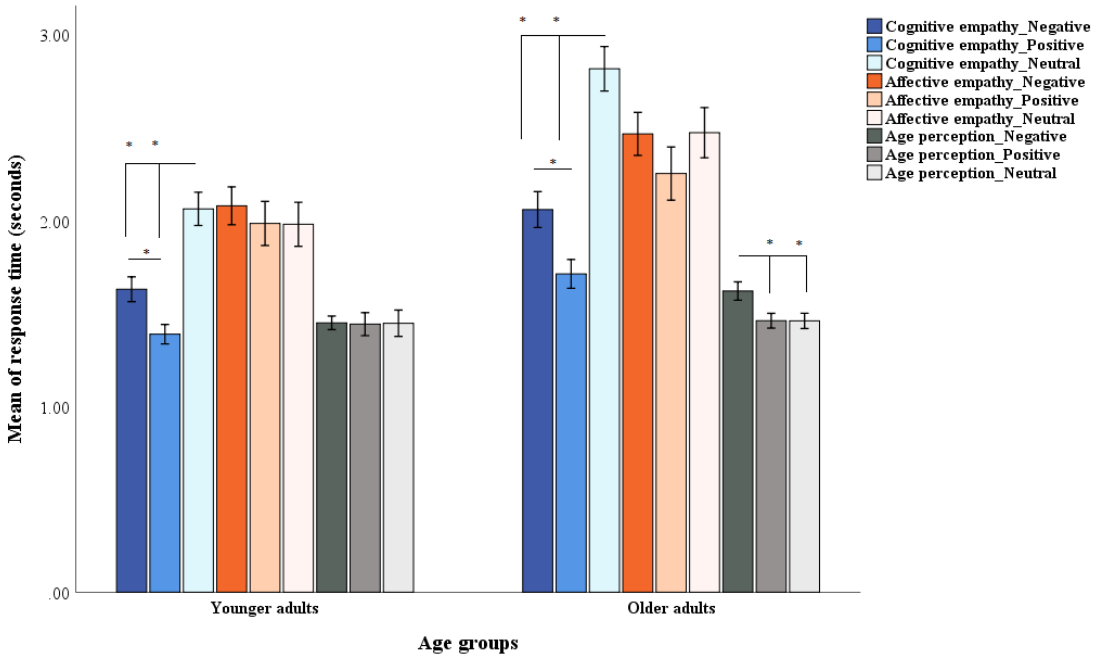

Cognitive empathy_Negative
Cognitive empathy_Positive
Cognitive empathy_Neutral
Affective empathy_Negative
Affective empathy_Positive
Affective empathy_Neutral
Age perception_Negative
Age perception_Positive
Age perception_Neutral
Mean of response time (seconds)
3.00
2.00
1.00
.00
Younger adults
Older adults
Age groups

Figure 4

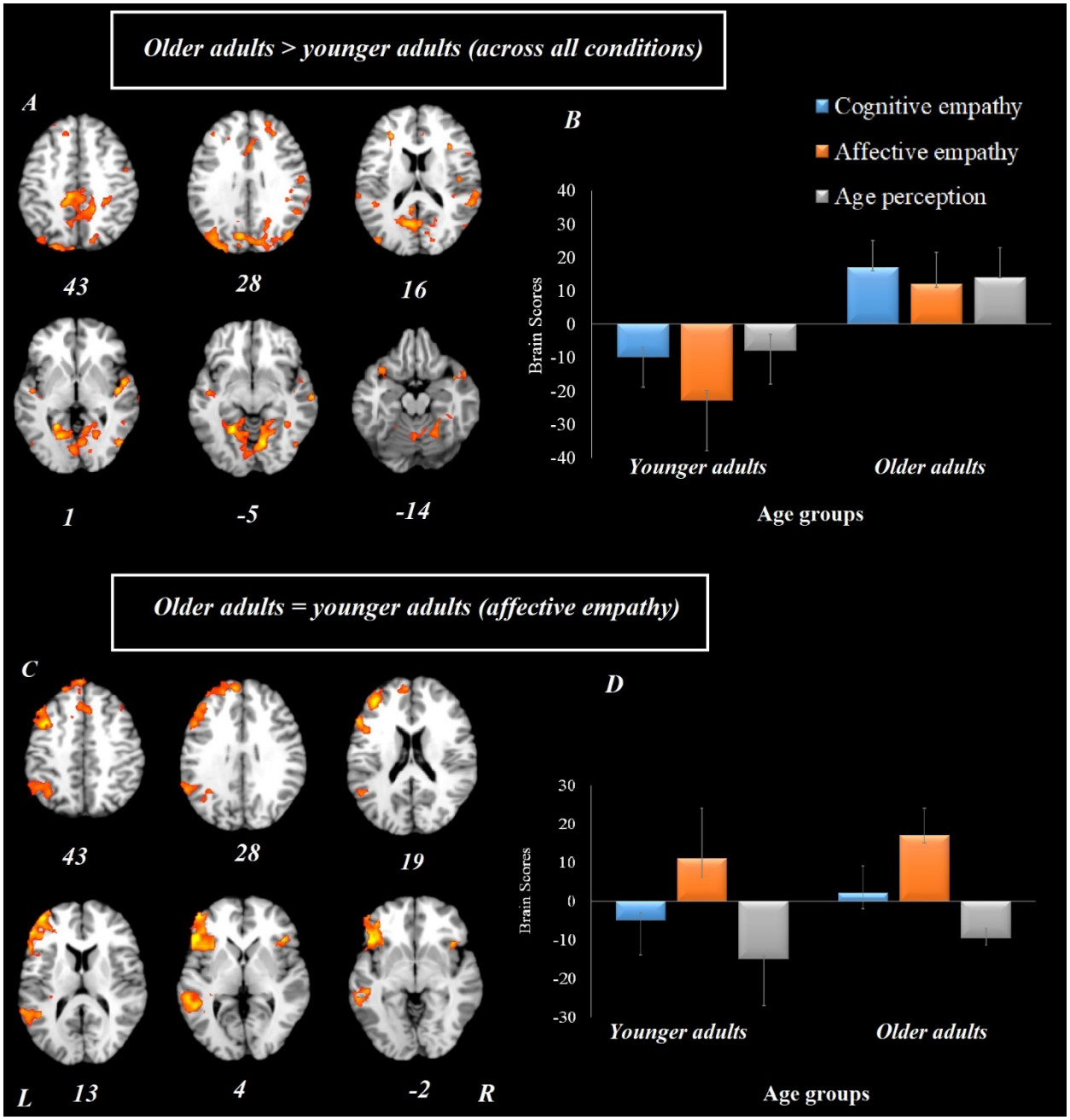
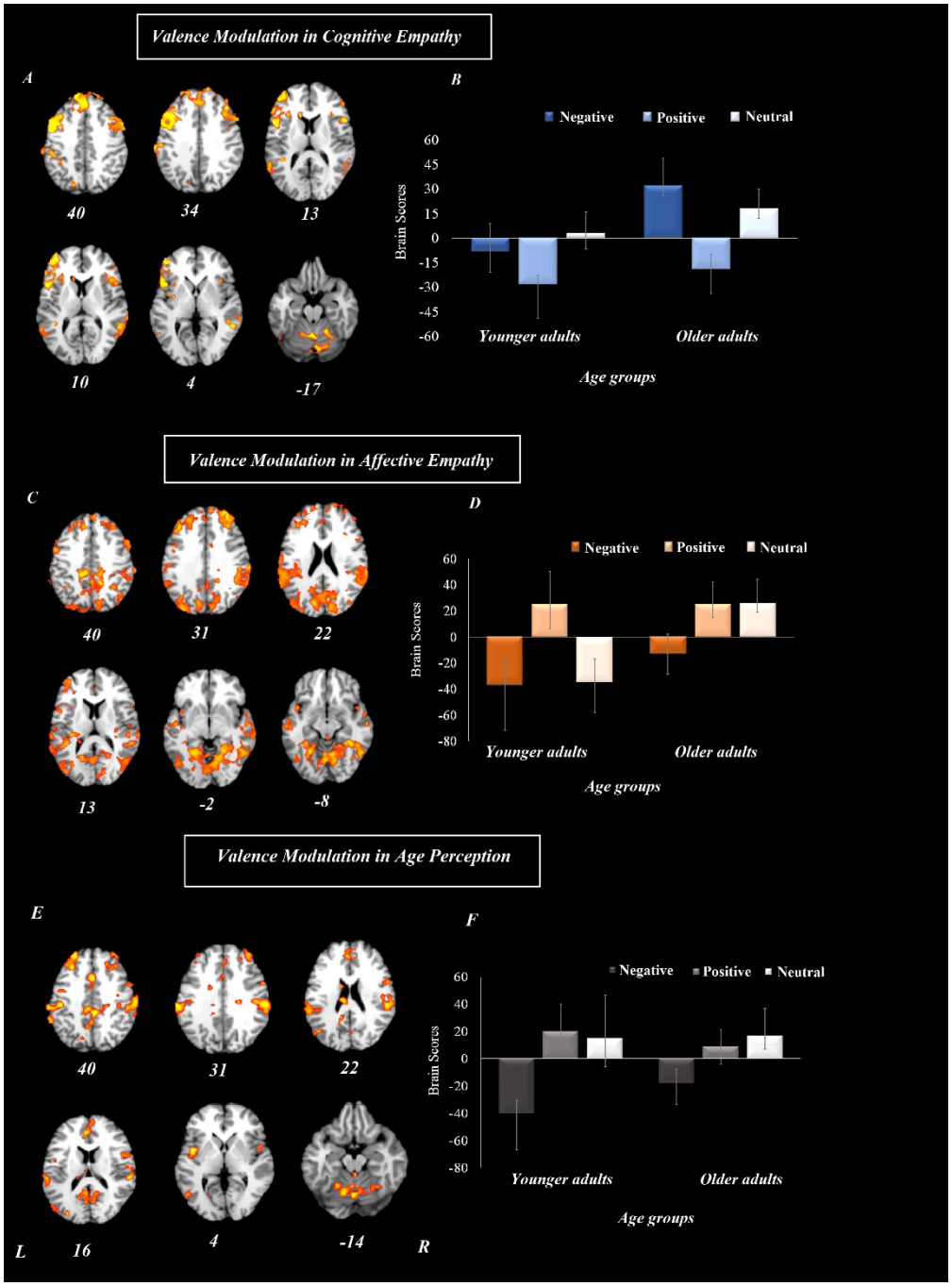

Older adults > younger adults (across all conditions)
A
43
28
16
1
-5
-14
B
Cognitive empathy
Affective empathy
Age perception
Brain Scores
40
30
20
10
0
-10
-20
-30
-40
Younger adults
Older adults
Age groups
Older adults = younger adults (affective empathy)
C
43
28
19
13
4
-2
L
R
D
Brain Scores
30
20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

Figure 5


Valence Modulation 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 Modulation 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 Modulation 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

Captions

Figure 1. Summary of predictions and hypotheses for cognitive and affective empathy conditions with positive and negative stimuli. TPJ = temporoparietal junction; ACC = anterior cingulate cortex; vmPFC = ventromedial prefrontal cortex PCC = posterior cingulate cortex; dmPFC = dorsomedial prefrontal cortex; O = older adults; Y = younger adults.

Figure 2. 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 face images. Each condition started with a 3-second instruction, followed by 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 3. 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. 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, negtive, 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 simuli 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.

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
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 regions modulated by valence across younger and older participants

Regions	Hem	MNI coordinates X Y Z	BSR
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.