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Similar neural networks for anger and pride in older adults

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ABSTRACT

There has been a significant amount of research on the neural mechanisms underlying "basic emotions" but relatively less research on complex social emotions like pride, embarrassment, guilt, or shame. The aim of this study was to investigate age-related differences in the neural basis of processing anger, joy, pride, and embarrassment, and possible association with well-being measurements, such as depression, anxiety and stress. Twenty-four younger and twenty-five older adults underwent functional imaging while viewing videos of four emotions and indicating the emotion expressed. Using multivariate analysis (Partial Least Squares), we found that older adults engaged a similar network for both anger and pride, while younger adults recruited two separate networks for positive vs. negative emotions, regardless of whether the emotion was basic or social. Furthermore, older adults with higher stress scores and younger adults with higher depression scores, as measured by the Depression, Anxiety, Stress Scale (DASS-21), activated a similar brain network during recognition of embarrassment. These findings suggest that both pride and anger are emotionally salient and require similar cognitive and attentional resources in older adults, while younger adults' neural activity is modulated by the valence, rather than the social content of stimuli. Our results also highlight the importance of considering age when studying the neural basis of complex, self-conscious, emotions and their association with well-being measurements.

1. Introduction

Emotions are often separated into two categories, either basic or social (Scarantino and Griffiths, 2011). Basic emotions are defined as emotions that are used to deal with fundamental life tasks such as handling social interactions, remembering past events, or reacting to physical experiences (Ekman, 1999), while social emotions depend on other people's thoughts, feelings, or actions (Hareli and Parkinson, 2008). Though many perspectives exist regarding which emotions constitute basic emotions, Paul Ekman's classification of anger, disgust, fear, happiness, sadness, and surprise as the six basic emotions remains the most widely applied (Ekman, 1992). Meanwhile, social emotions include a much wider range of emotions, including positive emotions such as pride and gratitude or negative emotions such as shame, guilt, and embarrassment (Bastin et al., 2016). The literature suggests that individuals of different ages recognize and encode emotions differently. In particular, further evidence from adult lifespan and aging research support the view that older adults are biased against attending to negative information (e.g., negative faces; Mather and Carstensen, 2003), and that older adults remember negative stimuli less well (Charles et al., 2003; see also Petro et al., 2021; Reed et al., 2014). This phenomenon has been referred to as the "positivity effect", which is possibly associated with age-related changes in the function of amygdala, and its network, (Petro et al., 2021; Reed et al., 2014) and may be related to older adults' downregulation of negative emotions (Mather and Carstensen, 2003; Ziaei et al., 2017).

However, the extent to which this positivity bias extends to the recognition of complex social emotions remains underexplored.

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Relatively less well-known are the age-related differences in processing complex social emotions (Bastin et al., 2016). Most previous studies on emotional processing across the lifespan are limited by the fact that they displayed only basic emotions and not many studies have included complex, social emotions such as pride, and embarrassment among the aged population, limiting our understanding of the neural substrates of complex social emotions. Social emotions have distinct neural mechanisms compared to basic emotions and may be experienced and recognized differently. For example, embarrassment is associated with sudden, accidental violations of social norms and is motivated by a desire to maintain one's social reputation. A meta-analytic overview showed that embarrassment was associated with activity of the dorsomedial prefrontal cortex (dmPFC), ventrolateral PFC (vlPFC), and amygdala (Bastin et al., 2016). These areas are highly associated with emotional processing and self-regulation, and are part of an emotion regulation network (Underwood et al., 2021; Xu et al., 2021). Previous studies have suggested that embarrassment might be more socially adaptive, concerns one's self image, and generates less emotional pain compared to shame and guilt (Bastin et al., 2016).

Pride is on the other hand the only positive emotion which leads people to reinforce their self and repeat the pride-causing behavior; pride often serves as a motivator for higher achievement and promotes social status. Pride requires a self-evaluative process relying on two cognitive capacities: objective self-awareness, which directs attention introspectively and treats oneself as valuable objects, and internalized standards of behavior, which could be generated from one's own experience or others' feedback (Lewis et al., 1992). Research differentiates two facets of pride: hubristic and authentic (Tracy and Robins, 2004, 2007). Hubristic pride is less attached to one's achievement but rather more reliant on narcissism and self-defensive mechanisms resulting from low self-esteem, while authentic pride is related to actual achievement and generally positive. Authentic pride correlates with self-esteem, and also prosocial. Neuroimaging research suggests that experiencing pride is linked to self-referential, reward, and affective processing (Roth et al., 2014), and requires the ability to detect intention of others (Takahashi et al., 2008).

While there is some evidence of a detrimental effect of poor social perception on social network support, employment, and mental health in the general population (Henry et al., 2023) as well as a link between greater emotion recognition abilities and mental and behavioral health outcomes in children (Wells et al., 2021), there is surprisingly little research on the link between ability to perceive social emotions and well-being in older adults (Henry et al., 2022). Prior research supports that abnormalities in reading facial expressions are associated with psychiatric and neurodegenerative disorders (Brown et al., 2020), depression (Demenescu et al., 2010), and schizophrenia (Kohler et al., 2003). For example, patients with depression were shown to be less accurate at recognizing emotions from faces than healthy controls, with changes in activity patterns within the limbic system likely to explain this effect (Krause et al., 2021). Also, individuals with deficits in emotion recognition have been shown to have low levels of life satisfaction and high levels of negative affect (Timoney and Holder, 2013); an effect that has been replicated across age ranges and different cultures (Aka and Gencoz, 2014; Antinienė and Lekavičienė, 2017; Rojahn et al., 1995). However, it currently is still largely unknown whether age-related differences in perceiving social emotion exist and if so, whether they are related to emotional well-being.

Thus, the present study set out to investigate age-related differences in processing social emotions, such as pride and embarrassment, and to determine their neural underpinnings using functional Magnetic Resonance Imaging (fMRI). The study furthermore aimed at determining the extent to which measurements of well-being, such as depression, anxiety, and stress, may be associated with the ability to recognize both basic and social emotions. To address these research questions, younger and older adults underwent brain imaging while viewing short clips that showed individuals expressing both basic (anger, joy) and social (pride, embarrassment) emotions and were asked to recognize the emotions displayed from the clips. Our participants were asked to identify emotional expression displayed in the videos rather than focusing on their own emotional responses to the stimuli. While it is still difficult to differentiate processes unique to recognition of emotions from the experience of emotions from faces, the primary focus here was on the recognition of emotions as previous studies have shown that recognizing emotions in others and experiencing them, i.e., affective empathy, engage partially overlapping but distinct neural networks (Ziaei et al., 2021, 2022). By focusing on recognition of emotions, we can more precisely identify age-related neural processes that facilitate social interactions, thereby contributing to our understanding of how recognition of complex social emotions evolves across the lifespan.

Given the scarcity of previous evidence regarding the involved neural mechanisms in processing social emotions in late adulthood, we set out some general hypotheses and anticipated age-related differences to be minimal for social emotions and that this effect might be modulated by the emotional valence in both age groups. We further hypothesized that higher psychopathology scores will be associated with processing of negative emotions, such as embarrassment and anger, as individuals with frontal lobe dysfunction often show diminished understandings of embarrassment, impairing adaptive functioning and creating symptoms of psychological disorders (Jankowski and Takahashi, 2014). Overall, this is the first study that aims to fill the gap in the literature by investigating age-related differences in neural networks involved in perception of social emotions and examining the association between recognizing social emotions and psychological well-being in both age groups including both genders.

2. Methods

2.1. Participants

Twenty-six younger and 25 older adults were recruited in this study. Two younger adults were excluded due to large head motion, leaving a total of 24 younger (mean age = 21.83 yrs, SD = 3.85 yrs, 12 female) and 25 older (mean age = 71.52 yrs, SD = 3.81 yrs, 14 female) adults. The younger adults were undergraduate students at the University of Queensland and were compensated with course credits, while the older adults were volunteers from the community who were compensated with $20 AUD per hour. All participants were screened for MRI compatibility, claustrophobia, mood disorders, and medication use, and were required to have normal or corrected-to-normal vision and no history of psychiatric illnesses, cardiovascular disease, head or heart surgery, or neurological impairment. Both age groups had similar levels of education and gender representation. The older adults also underwent cognitive screening using the Mini Mental State Examination (Folstein et al., 1975), and all scored above the recommended cut-off of 27 (mean score = 28.76, SD = 1.26). Participants took part in two separate sessions, one involving fMRI scanning and the other involving behavioral and neuropsychological assessments. The study received ethical approval from the Royal Brisbane and Women's Hospital Research Ethics Committee and the University of Queensland and all participants provided written informed consent and were debriefed after the second session. In addition, ethical approval for the use and analysis of the data collected was given by the Norwegian Regional Committee for Medical and Health Research Ethics.

2.2. Experimental procedure

The study consisted of a 1-h MRI session followed by a 2-h behavioral and neuropsychological assessment on the same day. Before the MRI session, participants received verbal instructions about the task and completed practice trials to become familiar with the trial timing and task sequence. After the MRI, they completed several psychological measures (related to cognition, empathy, depression, anxiety, and stress), were debriefed, and received compensation.

2.3. Emotion recognition task

Participants were asked to recognize emotional expressions of faces presented in video clips by choosing as fast and accurately as possible one of four possible responses: anger, joy, pride, or embarrassment. For each emotion, 12 videos were included in each run, with a total of 3 runs, resulting in a total of 144 videos. Video clips from the Amsterdam Dynamic Facial Expression Set (ADFES) were used (van der Schalk et al., 2011). Each video clip lasted 6s in which neutral expressions were presented for 0.5 s followed by the onset of the emotional expression and the full emotional expression held for 5s (Fig. 1). All the videos were face-forward version, and all models were non-Caucasian, with both male and female models. Following each video, a cross with a jittered inter trial intervals ranging from 0.5 to 2s was presented. The order of runs was counterbalanced among participants and the order of trials within each run was pseudo-randomized. No more than two of the same emotion and gender were presented consequently within each run.

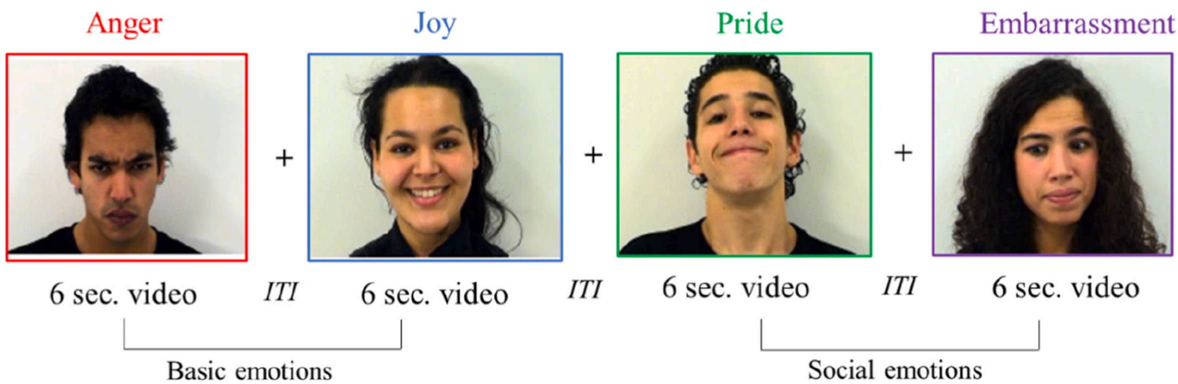

Fig. 1. Experimental design for the emotion recognition task. Each video displayed one of four emotion expressions: anger, joy, pride and embarrassment. The expression evolved from neutral to the target emotion within 6 s and participants were asked to indicate which emotion was expressed by pressing the respective button as soon as they recognized the emotion in the video. *ITI* = inter-trial interval, Sec = second.

Table 1
Descriptive data (means and standard deviations) and inferential statistics for demographic and psychological measures in younger and older adults.

	Younger Adults (N = 24)		Older Adults (N = 25)		Age-Group Differences	
	M	SD	M	SD	T	df
Demographics						
Age (years)	21.83	3.85	71.52	3.81	45.39**	47
Education (years)	15.6	2.46	17.34	8.79	0.93	47
Executive Functioning						
Verbal Fluency Test	47.84	10.68	53.20	12.43	1.64	48
Stroop Interference	0.24	0.26	0.29	0.19	0.70	47
Task Switching Index	20.8	8.83	24.86	12.00	1.35	47
Raven IQ	6.40	1.78	5.68	1.97	1.35	48
Emotional Well-Being						
DASS-21						
Stress	10.25	6.05	3.52	3.84	4.66**	47
Anxiety	5.17	3.77	0.96	1.54	5.15**	47
Depression	6.83	6.77	1.28	2.30	3.87**	47
Empathy						
IRI						
Fantasy	16.04	4.79	13.64	5.42	1.64	47
Empathic concern	17.88	3.71	18.68	3.56	0.78	47
Perspective taking	19.62	4.09	19.64	3.44	0.01	47
Personal distress	12.00	5.79	8.64	4.32	2.31*	47
EQ	44.44	11.17	49.08	11.45	1.45	48
RMET	25.96	4.18	27.72	4.37	1.44	47
Social emotion test reaction times (ms)						
Anger	2398.89	217.48	2876.02	349.09	5.71**	47
Joy	2391.51	217.53	2665.85	241.02	4.17**	47
Pride	2682.09	330.23	3137.70	313.50	4.95**	47
Embarrassment	2605.45	307.35	2991.60	410.30	3.76**	47
Correct response (%)						47
Anger	0.98	0.02	0.95	0.09	1.15	47
Joy	0.98	0.02	0.97	0.06	0.57	47
Pride	0.88	0.07	0.90	0.08	0.90	47
Embarrassment	0.97	0.02	0.96	0.08	0.76	47

Note: *p < 0.05, **p < 0.001. Verbal Fluency Test (Benton and 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 and Wolfson, 1986): Trail Making Test Part B – Trail Making Test Part A; Raven IQ = total number of correct responses; DASS-21 = Depression Anxiety Stress Scale (Lovibond and Lovibond, 1995); IRI = Interpersonal Reactivity Index (Davis, 1983); EQ = Empathy Quotient (Baron-Cohen and Wheelwright, 2004); RMET = Reading the Mind in the Eyes Test (Baron-Cohen et al., 2001); M = mean; SD = standard deviation; df = degree of freedom.

2.4. Psychological measures

In the psychological assessment session, participants completed tasks related to executive functioning such as the Stroop Task (Jensen and Rohwer, 1966), abbreviated Raven's Progressive Matrices (Bilker et al., 2012), Trail Making Test (Reitan and Wolfson, 1986) (Reitan and Wolfson, 1986), and a verbal fluency measure (Newcombe, 1969). Their emotional well-being was measured using the Depression, Anxiety, Stress Scale (DASS-21; (Lovibond and Lovibond, 1995). Participants were also tested on empathy and theory of mind using the Empathy Quotient (EQ; Baron-Cohen and Wheelwright, 2004), Interpersonal Reactivity Index (IRI; Davis, 1983), and the Reading the Mind in the Eyes test (RMET; Baron-Cohen et al., 2001). As shown in Table 1, there were no significant differences between the two age groups in these psychological measures, except for all three measures of the DASS-21 (*ps* < 0.001) and the personal distress subscale of the IRI ($p < 0.05$), for which younger adults reported higher scores than older adults.

2.5. MRI image acquisition

Functional images were acquired on a 3 T Siemens Prisma scanner with a 32-channel head coil at the Centre for Advanced Imaging, University of Queensland. A T2*-weighted multiband sequence was used for whole-brain imaging (595 interleaved slices, repetition time = 612 ms, echo time = 30 ms, voxel size = 2.5 mm^3, field of view = 190 mm, flip angle = 52°, multi-band acceleration factor = 5). High-resolution T1-weighted images were collected using an MP2RAGE sequence (176 slices per slab, TR = 4000 ms, voxel size = 1 mm^3, TE = 2.91 ms, TI = 700 ms, FOV = 256 mm, PAT mode = GRAPPA). To reduce noise and head motion, participants were given earplugs and cushions around their heads inside the head coil. The task was presented to participants on a computer screen through a mirror mounted on top of the head coil, and they responded to the task using an MRI compatible response box.

3. Analyses

Preprocessing of fMRI data. Preprocessing was performed on T2*-weighted images using Statistical Parametric Mapping Software (SPM12) in MATLAB 2017a. The images were first realigned to a mean image to correct for head motion, and then segmented into gray and white matter. They were normalized to a standard stereotaxic space with a voxel size of 2 mm^3 and spatially smoothed using a Gaussian kernel with a 6 mm^3 full width at half maximum.

Whole-brain analysis using PLS. To examine differences in brain activity between younger and older adults during the different experimental conditions (positive comprising pride and joy and negative comprising embarrassment and anger), we used Partial Least Squares (PLS) analysis (Krishnan et al., 2011; McIntosh et al., 2004). Partial Least Squares (PLS) utilizes singular value decomposition (SVD) of a unified matrix that combines data from all experimental conditions and participants to identify a set of orthogonal variables known as latent variables. Typically, the first latent variable captures the highest amount of covariance in the data, with each subsequent latent variable accounting for progressively less covariance. These latent variables collectively characterize the brain activity associated with the experimental conditions. Each latent variable provides insights into the extent to which each participant contributes to the pattern represented by that variable, a measure referred to as brain scores. These brain scores are determined by calculating the dot product of a participant's image volume with each latent variable. Typically, the first latent variable (LV) captures the largest amount of covariance in the data, with each subsequent LV accounting for progressively smaller portions of the covariance. Each LV is composed of three key elements: a spatiotemporal pattern of brain activity known as voxel saliences, a set of weights referred to as task saliences that indicate the relationship between the experimental conditions and brain activity, and the amount of covariance explained by the LV, which is known as the singular value. Thus, each LV includes brain scores that indicate how strongly each participant contributed to the pattern represented by that LV and whether the pattern was reliable (if confidence intervals obtained from bootstrap ratio crossing zeros, they are regarded as unreliable results for any given LV). For the whole-brain analyses, both age groups and all experimental conditions were included in the analyses simultaneously and results reveal similarities or differences between the two age groups in each experimental condition based on the data, as opposed to imposed contrast as in traditional univariate models such as General Linear Model.

Brain-behavior analysis using PLS. We followed similar analyses as our previous work using PLS for brain-behavior relationships (Ziaei et al., 2016, 2020, 2022). In addition to the whole-brain analysis, we conducted a separate brain-behavior PLS analysis than the whole-brain analysis. We investigated the extent to which the ability to recognize social emotions was related to self-report measures of well-being using the DASS-21 for younger and older adults. We calculated the correlation between brain scores from each significant latent variable (LV) and the behavioral responses in DASS-21 measurement during social emotion conditions. The results present the Pearson correlation coefficient between brain scores and other variables as follows: (i) brain activity for younger and older adults under each social emotion condition; and (ii) brain activity correlated with DASS-21 subscores for each age group. These correlations reflect a two-way relationship between brain function and behavior. The statistical significance of each latent variable was determined using a permutation test, which evaluates the probability of a singular value based on 500 random reorderings and resampling (McIntosh et al., 2004). Furthermore, to assess the reliability of the saliences for each brain voxel, we estimated the standard error of each voxel's salience on each latent variable through 100 bootstrap resampling steps (Efron and Tibshirani, 1985). Peak voxels with a bootstrap ratio (i.e., salience divided by standard error) greater than 2.5 were considered reliable, as this threshold approximates $p < 0.01$ (Sampson et al., 1989). Lastly, given that PLS is a multivariate approach that not only analyzes multiple conditions simultaneously to examine covariance of responses across conditions but also considers all voxels simultaneously, no multiple comparison correction is necessary (McIntosh et al., 2004). Additionally, we conducted 5000 iterations of the permutation test, and the results were consistent with those obtained from 500 iterations, thus, we are reporting the findings using 500 iterations in the results.

Behavioral responses in the Emotion recognition task. We conducted two-way ANOVAs with age group as between-subjects factor, emotional expression as within-subjects factor, and response times or accuracy as the dependent variable. In addition, we performed two-sample *t*-tests to follow up the effects from ANOVA analyses and for behavioral measures reported in Table 1.

4. Results

4.1. Age differences in response times during emotion recognition

A two (age group; younger and older adults) by four (emotion; anger, joy, pride or embarrassment) ANOVA revealed a significant main effect of age group ($F(1,47) = 28.87$, $p < 0.001$, $\eta_p^2 = 0.37$) and emotion ($F(3,141) = 44.09$, $p < 0.001$, $\eta_p^2 = 0.48$) on response times (RTs). The interaction of age group and emotion was also significant ($F(3,141) =$

3.22, $p = 0.02$, $\eta_p^2 = 0.06$). Older adults responded slower than younger adults in all emotions and joy was faster to be recognized compared to all other emotions (all *ps* < 0.05). Among younger adults, within negative emotions, recognition of embarrassment took longer compared to anger ($t(23) = 1.27$, $p = 0.21$, $d = 0.52$) and within positive emotions, pride took longer compared to joy ($t(23) = 0.23$, $p = 0.81$, $d = 0.09$). No differences were found between RTs of social emotions (embarrassment compared to pride) and basic emotions (anger compared to joy; all *ps* $>$ 0.05). On the other hand, among older adults, social emotions had longer RTs compared to basic emotions (all *ps* > 0.05) and while joy was faster to be recognized than anger within basic emotions ($t(24) = 3.77$, $p = 0.001$, $d = 1.53$), pride took longer to be recognized compared to embarrassment within social emotions ($t(24) = 2.59$, $p < 0.001$, $d = 1.05$; Fig. 2).

Another 2 (age group; younger or older) by 4 (emotion; anger, joy, pride, or embarrassment) ANOVA revealed no significant main effect of age group ($F(1,47) = 0.23$, $p = 0.63$, $\eta_p^2 = 0.005$) but a significant main effect of emotion ($F(3,141) = 21.14$, $p < 0.001$, $\eta_p^2 = 0.31$) on accuracy. Pride was recognized less accurately compared to other emotions (all *ps* < 0.001).

4.2. Whole-brain activity patterns: Similarity of anger and pride among older adults

Whole-brain analysis revealed two significant LVs. The first LV accounted for 33% of the variance in the data ($p < 0.001$) and revealed a pattern of brain activity recruited by older adults during anger and pride recognition (confidence intervals overlapping) This network included the right superior temporal gyrus, right inferior frontal gyrus, bilateral insula, right superior frontal gyrus, medial frontal gyrus, bilateral

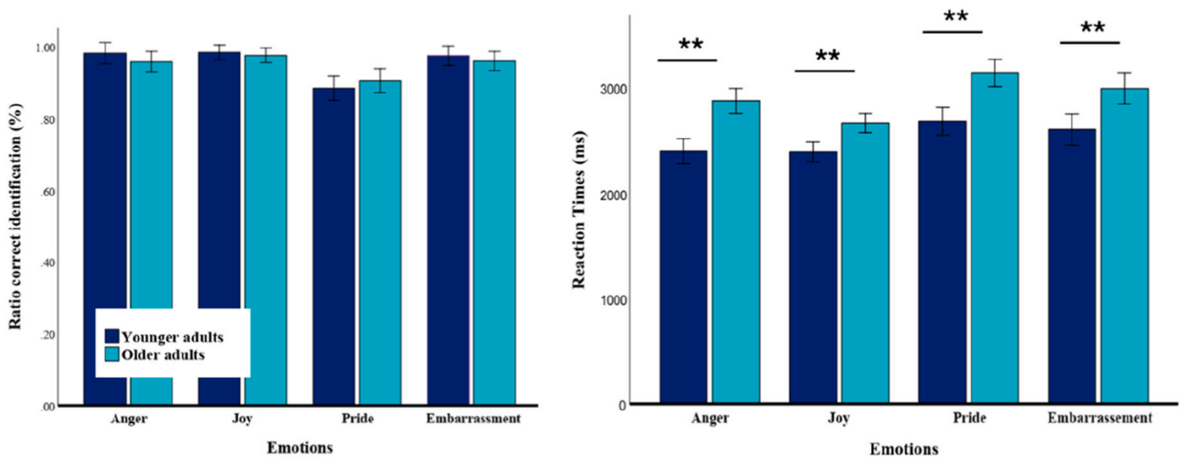

Fig. 2. Accuracy (A) and response times (B) by emotion and age groups. The ratio of correct responses was calculated based on the number of correct responses divided by all responses. Panel A shows that older adults identified pride significantly more accurate than younger adults (i.e., younger adults experienced difficulties in pride recognition compared to all other emotions). Panel B shows that older adults were overall slower in emotion recognition than younger adults. *$p < 0.05$, **$p < 0.01$. Error bars reflect the ± 2 standard error.

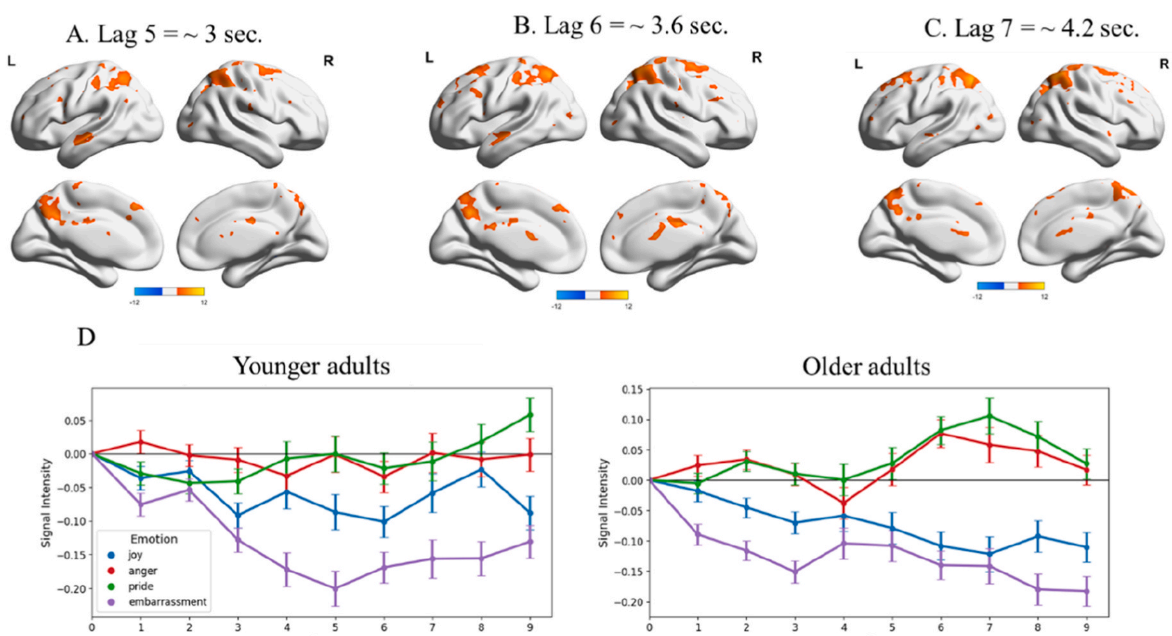

Fig. 3. Whole-brain activity pattern for anger and pride among older (but not younger) adults. Panel A–C represent neural activities across different lags/repetition times from the onset of the stimuli for anger and pride among older adults. Panel D shows the timeline of the signal intensity over lags/repetition times in the anterior cingulate cortex for younger and older adults as example to show how responses develop over time. For all reported regions a bootstrap ratio of ≥2.5 and a cluster size of ≥50 voxels were applied. L = left hemisphere, R = right hemisphere.

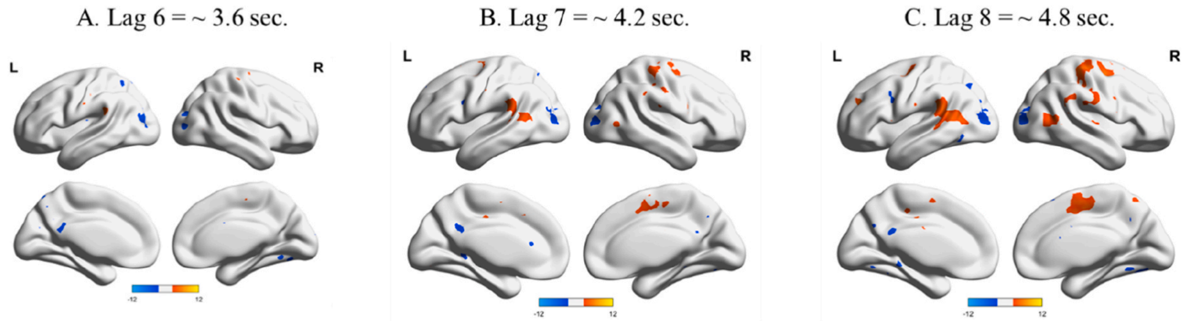

Fig. 4. Two distinct whole-brain brain activity patterns for anger/embarrassment vs. joy/pride among younger adults. Panels A-C represent neural activities across different lags/repetition times from the onset of the stimuli. The yellow/orange color indicates neural activity related to anger and embarrassment; and the blue color indicates neural activity for joy and pride. For all reported regions a bootstrap ratio of ≥2.5 and a cluster size of ≥50 voxels were applied. L = left hemisphere, R = right hemisphere. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

precuneus, bilateral inferior parietal lobe, and posterior cingulate cortex. Younger adults did not reliably engage this brain activity pattern (see Fig. 3).

4.3. Whole-brain activity patterns: Distinction based on emotional valence among younger adults

The second LV accounted for 11% of the variance in the data (p = 0.03) and revealed two brain activity patterns engaged by younger adults, which was modulated by the valence. One pattern was recruited during recognition of anger and embarrassment (yellow pattern in Fig. 4). This pattern included the bilateral superior and medial temporal gyrus, left inferior frontal gyrus, left medial temporal gyrus, and left medial frontal gyrus. The other pattern was recruited during joy and pride recognition. This pattern included the bilateral precuneus, posterior cingulate, and bilateral middle frontal gyrus (blue pattern in Fig. 4). Older adults did not reliably engage this brain activity pattern.

4.4. Brain-behavior relationship: Embarrassment processing and mental well-being

Separate analyses with the DASS-21 scores and brain activities furthermore revealed a significant LV that accounted for 21% of the variance in the data (p = 0.042). This latent variable was distinct from those identified in the whole-brain PLS model and specifically reflects the association between neural activation during emotion recognition and measures of well-being. This brain activity pattern was recruited by older adults who scored higher in stress and by younger adults who scored higher in depression during processing embarrassment. This pattern included the bilateral superior temporal gyrus, bilateral insula, postcentral gyrus, bilateral precuneus, right inferior parietal lobe, and right middle frontal gyrus.

5. Discussion

This study fills an important gap in the literature regarding neural networks involved in recognition of social (pride and embarrassment) relative to basic (joy and anger) emotions in both younger and older adults and speaks to the association between well-being (i.e., depression and stress) and underlying brain networks for processing complex social emotions.

In particular, our results indicate that older adults engaged a widespread network similarly for the processing of anger and pride while younger adults recruited two separate networks that differentiated between processing of positive vs. negative emotions, irrespective of these being basic or social. In particular, the network engaged by older adults for anger and pride included the right superior temporal gyrus, right inferior frontal gyrus, bilateral insula, right superior frontal gyrus, medial frontal gyrus, bilateral precuneus, bilateral inferior parietal lobe, and posterior cingulate (first LV). The positive emotion network in younger adults included the bilateral precuneus, posterior cingulate, and bilateral middle frontal gyrus; while the negative emotion network included the bilateral superior temporal gyrus, bilateral insula, postcentral gyrus, bilateral precuneus, right inferior parietal lobe, and the right middle frontal gyrus regions (second LV). Finally, our behavioral PLS analysis revealed that older adults with higher stress scores and younger adults with higher depression scores activated a similar brain network during processing embarrassment. This network included the bilateral precuneus, bilateral insula, middle frontal gyrus, bilateral superior temporal gyrus, and right middle frontal gyrus. The novel findings emerging from this work are discussed next.

5.1. Similarity of processing anger and pride among older adults

One of the most interesting findings of this study is that older adults recruit the same brain network for both pride and anger (as indicated in overlapping confidence internals for these two emotions), suggesting that both these emotions may be particularly salient and require significant attentional resources specially among older adults. Indeed, the network comprised inferior frontal gyrus, insula and superior and medial frontal regions confirming that additional processes including attentional control and cognitive control processes (e.g., see cognitive control network; Uddin et al., 2019), were required for processing these emotions among older adults. Our previous work has repeatedly shown that negative emotions including anger engages major nodes of the salience network such as the anterior cingulate and insula among older adults (Ebner et al., 2012; Ziaei et al., 2016, 2019). In this work, we have shown that major nodes of the salience/midcingulo-insular network were recruited among older adults not only during the recognition of negative emotion such as anger, but also during higher order social-cognitive functions such as affective empathy for negative emotions (Ziaei et al., 2021). The overlapping neural activation may reflect that both pride and anger are emotionally salient and require similar cognitive and attentional resources for processing in older adults' group. The engagement of regions such as the inferior frontal gyrus, insula, and superior frontal gyrus suggests that both emotions may involve enhanced emotional regulation and cognitive control mechanisms. This pattern differs from younger adults, who maintained distinct neural responses based on emotional valence, regardless of whether the emotion was basic or social. The absence of similar patterns for embarrassment among older adults suggests that the observed similarity is not merely a result of processing negative emotions. Instead, it may indicate that pride, as a complex social emotion, shares certain cognitive demands with anger that are particularly salient in older adults. Embarrassment, while also a social emotion, may involve different aspects of social cognition and self-awareness that do not overlap as significantly with anger or pride in terms of neural processing.

The cross-cultural literature differentiates two facets of pride: Authentic pride is elicited by controllable causes such as effort, is adaptive, prosocial and has been associated with a social profile (e.g. achievement related). In contrast, hubristic pride is experienced when individuals attribute their pride to ability and is associated with a maladaptive, anti-social profile (e.g., self-oriented) (Shi et al., 2015). Recruitment of the same brain network when processing pride and anger observed among older adults in the present study could suggest negative valence associated with expressing pride among our older adult study sample. In other words, expressing pride may have been perceived as less positive, and possibly more associated with hubristic than authentic in our Australian older adult sample, resulting in more negative evaluations of this emotion. In fact, the "Tall Poppy Syndrome," a phenomenon where individuals who express unwarranted self-adulation or excessive pride within Australian society may not be perceived as positive, may be present in our results and is an interesting explanation to explore in future research (Peeters, 2004). In addition, it important to note that the experience of pride and recognition of pride might be distinct. In this study, we primarily focused on recognition of these emotions rather than self-experiencing them. Future studies should investigate the similarities or differences between these two processes; i.e., experience or recognition of these emotions.

5.2. Distinction of emotional valence among younger adults

Intriguingly, our study revealed two distinct neural networks for processing positive (pride, joy) versus negative (embarrassment, anger) emotions among younger adults. In particular, a network, which included the bilateral superior temporal gyrus, bilateral insula, bilateral precuneus, right inferior parietal lobe, right postcentral gyrus, and right middle frontal gyrus regions resembling the frontoparietal network was activated for anger and embarrassment (Uddin et al., 2019). Engagement of this network aligns with previous studies supporting the role of these regions in the processing of anger, and also negative emotions more generally (Ochsner et al., 2004, 2009; Denson et al., 2009; Lindquist et al., 2012; Ziaei et al., 2016). Our results show that emotional valence (positive vs. negative) recruit different brain networks in younger adults, but not in older adults. These findings also corroborate previous evidence of differential network engagement for negative emotions in both emotion recognition and affective empathy between younger and older adults, but similar engagement for positive emotions (Morelli et al., 2015; Van Kleef, 2009; Ziaei et al., 2021, 2022). In particular, while our younger adults engaged the frontoparietal network for processing negative emotions, irrespective of the social or basic nature of the emotion, they engaged more posterior brain networks, including main nodes of the default mode network (e.g., posterior cingulate and precuneus), during processing of positive emotions. This suggests that younger individuals process emotions more categorically based on valence, whereas older adults may process certain emotions based on their cognitive and attentional demands.

Our behavioral data showed that, younger adults were more accurate in the recognition of negative than positive emotions; with this effect particularly pronounced for pride. Previous work has shown that children cannot recognize pride until after the age of 4 and this ability continues to improve with age (Tracy et al., 2005). It is only until the age of 10 when children can fully recognize and attribute pride to certain actions, with this ability improving over time (Tracy et al., 2020). That is, pride, as a rather complex emotion and may require more cognitive effort to recognize than other emotions. The present study, however, cannot directly speak to the extent to which pride may have been more difficult for younger adults to be recognized than the other social emotions studied here; an explanation that future research will need to systematically address.

5.3. Recognition of embarrassment and mental well-being in younger and older adults

A third interesting result that emerged from this study pertained to the brain-behavior relationship between neural network activation (i.e., comprising the insula, middle frontal gyrus, and superior temporal gyrus) and embarrassment recognition as a function of age and DASS-21 scores. These regions has been shown to be involved in self-referential processing, orientation of attention and discrimination between self versus others. In older adults, this network was activated with greater stress scores while younger adults displayed activation alongside higher depression scores. We speculated that this network may be related to regulating difficult emotions, which it filters out negative stimuli depending on the age group. Older adults in particular are vulnerable to stress and that activation of the vmPFC is often related to controlling feelings of stress and emotional reactivity (Thayer et al., 2021). Younger adults, on the other hand, often activate regions such as the ACC and the anterior insula more when recognizing embarrassment and experiencing second-hand social pain (Krach et al., 2011). Social isolation and dysfunction are large components of conditions such as depression, and embarrassment would serve as a guardrail against maladaptive social behavior (Porcelli et al., 2019). Thus, more studies are needed to investigate these effects in detail in both healthy and clinical populations. Future research with larger and more diverse samples is necessary to validate these associations and to better understand the distinct and shared neural mechanisms underlying different aspects of well-being in relation to social emotions specifically.

5.4. Limitations and future directions

While we generate several novel findings that advance understanding of the neural substrates underlying the recognition of complex emotions in younger and older adults, the present study has some limitations that can be addressed in future research. First, the selection of emotions was limited and did not include other social emotions such as guilt or shame. It is important to acknowledge that our study focused solely on two social emotions: pride and embarrassment. While these emotions are representative of positive and negative social emotions, respectively, they do not encompass the full spectrum of social emotions, such as guilt, shame, or gratitude. Future research should aim to include a broader range of social emotions to fully understand the neural underpinnings of complex emotional processing across different age groups. Additionally, while we utilized video stimuli, the length of these clips was too short (only 6 s) for dynamic functional connectivity or other time-based methods, which would have allowed a (fine-grained) temporal analysis of the identified underlying substrates. Moving forward, we also suggest other studies to use methods such as movie fMRI with longer duration for videos, which may produce more consistent age-effects across different emotions (Ye et al., 2023). It would also be interesting in future research to follow up on our speculation that pride may have been particularly difficult for younger adults. Future studies should systematically vary stimuli and task format to determine if the recognition of social/complex emotions requires more cognitive effort than the recognition of basic emotions. Specifically, changing the instructions to explicitly differentiate neural substrates associated with experience or recognition of social emotions. Finally, our study was limited to a sample of Australian younger and older adults, and high functioning older individuals, and thus cannot speak to effects in other age groups (e.g., middle-aged adults, adolescents) nor more diverse individuals from a wider cultural and cognitive range, which constitutes a relevant research question given growing evidence of cultural differences and cognitive functioning in the recognition (as well as the experience and expression) of social emotions (Robins and Schriber, 2009).

6. Conclusion

Overall, our results shed light on age-related differences in processing of basic as well as more complex, social emotions, namely anger, joy, pride, and embarrassment. We found that older adults engaged a distinct network when processing anger and pride in comparison with younger adults, and this network is reflective of attentional and cognitive control demands when processing these emotions. In addition, we found that younger adults recruited two separate networks for positive and negative emotions, a network resembling the frontoparietal network for negative and one with nodes of the default mode network for positive, irrespective of their basic versus social nature. Furthermore, we found that older adults with higher stress cores and younger adults with higher depression scores on DASS-21 activated a neural network that resembles the default mode network for processing embarrassment. These findings differentiate the relationship between embarrassment and mental health symptoms as a function of age. Future research should examine whether interventions targeting self-conscious emotion processing could improve social functioning and mental health in older adults and include video stimuli of a longer length to enable dynamic functional connectivity analysis to investigate how emotion perception for both basic and complex emotions evolve over time.

CRediT authorship contribution statement

Jae S. Hong: Writing – original draft, Methodology, Investigation. **Leona R. Bätz:** Writing – review & editing, Visualization, Methodology, Formal analysis. **Shuer Ye:** Writing – review & editing, Visualization, Methodology, Formal analysis. **David C. Reutens:** Writing – review & editing, Resources, Funding acquisition. **Natalie C. Ebner:** Writing – review & editing, Conceptualization. **Maryam Ziaei:** Writing – original draft, Supervision, Formal analysis, Data curation, Conceptualization, Funding acquisition.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.neuropsychologia.2025.109087.

Data availability

Link to codes used for processing imaging data hosted on Open Science Framework.

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