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The Relationship Between Early and Recent Life Stress and Emotional Expression
Processing—A Functional Connectivity Study

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Abstract

The aim of this study was to characterize neural activation during the processing of negative facial expressions in a non-clinical group of individuals who experienced only early life stress, only recent life stress, both, or neither. Two models of stress consequences were investigated: the match/mismatch and cumulative stress models. The match/mismatch model assumes that early adversities may promote optimal coping with similar events in the future through fostering the development of coping strategies. The cumulative stress model assumes that effects of stress are additive, regardless of the timing of the stressors. Previous studies have suggested that stress can have both cumulative and match/mismatch effects on brain structure and functioning and, consequently, we hypothesized that effects on brain circuitry would be found for both models. We anticipated effects on the neural circuitry of structures engaged in face perception and emotional processing and, hence, the amygdala, fusiform face area, occipital face area, and posterior superior temporal sulcus were selected as seeds for seed-based functional connectivity analyses. We found that both the interaction between early and recent life stress, as well as cumulative stress levels, were related to alterations in functional connectivity during emotional facial expressions processing. This study adds to the growing body of literature suggesting that both the cumulative and the match/mismatch hypotheses are useful in explaining the effects of stress on humans.

Keywords: stress, faces, emotional expression, mismatch hypothesis, cumulative stress, functional connectivity

Introduction

Affective processing is crucial for both social interaction and avoiding threats. Emotional facial expressions carry important social information and can excite emotions in other people (Campos, Frankel, & Camras, 2004). Efficient recognition and processing of emotional facial expressions facilitates social communication (Frith, 2009). It is known that both acute (van Marle, Hermans, Qin, & Fernández, 2009) and past stress (Nusslock & Miller, 2016; Pechtel & Pizzagalli, 2011), as well as various psychiatric conditions (Joormann & Gotlib, 2007; Larøi, Fonteneau, Mourad, & Raballo, 2010; Masten et al., 2008) may alter emotional processing, including the processing of facial expressions.

Processing of emotional expressions involves the activation of a broad neural network (Bernstein & Yovel, 2015). The fusiform face area (FFA), occipital face area (OFA), and posterior superior temporal sulcus (pSTS) are important regions responsible for face detection and play an essential role in the processing of emotional expressions (Duchaine & Yovel, 2015; Haxby, Hoffman, & Gobbini, 2000). While the fusiform gyrus is activated in response to face stimuli, regardless of facial expression (Tong, Nakayama, Moscovitch, Weinrib, & Kanwisher, 2000), it is also involved in the processing of emotional expressions (Ganel, Valyear, Goshen-Gottstein, & Goodale, 2005). Indeed, a recent review has confirmed that there is an overlap between facial identification and expression processing, and that both FFA and pSTS are particularly engaged in these processes (Lander & Butcher, 2015). However, the processing of emotional facial expressions also engages an extensive neural network associated with emotional processing (Duchaine & Yovel, 2015; Haxby et al., 2000). Fusar-Poli et al. (2009), in their meta-analysis, reported increased reactivity to emotional faces in the fusiform gyrus, middle temporal gyrus (MTG), middle occipital gyrus (MOG), and in subcortical structures such as the amygdala, putamen, and caudate nucleus.

Adversities in early life can have a long-term impact on brain functioning which, in turn, often affects emotional processing. Hence, individuals who have experienced early adversities often exhibit altered neural activation in response to emotional faces. This is especially true for the activity of the amygdala, which is a structure heavily implicated in affective processing. Childhood maltreatment, institutionalization, caregiver deprivation, and negligence have been shown to be positively correlated with amygdala activation in response to both negative (Dannowski et al., 2012; Maheu et al., 2010; McCrory et al., 2013; Tottenham et al., 2011) and positive facial expressions (McCrory et al., 2013; but see Taylor, Eisenberger, Saxbe, Lehman, & Lieberman, 2006). For instance, Gollier-Briant et al. (2016) found a positive relationship between lifetime distress and adolescents' brain activation while viewing angry faces in the inferior frontal gyrus (IFG), middle frontal gyrus (MFG), orbitofrontal gyrus (OFC), MTG, and superior temporal gyrus (STG).

Life stress may lead to both dendritic and synaptic remodelling of brain regions involved in emotional processing (for review, see McEwen et al., 2015). This can contribute to altered functional connectivity—i.e., the way that the activity of distinct brain regions is correlated in time—during processing of emotional expressions. Interpreting functional connectivity can provide insight into how neurons and neural networks process information. In a study using emotional facial stimuli with children and adolescents who had experienced institutionalization, a negative correlation was observed between the activity of the amygdala and medial prefrontal cortex (mPFC), which is normally characteristic of a more mature brain (Gee et al., 2013). In another study, positive correlation between the activity of the amygdala and the hippocampus, inferior IFG, medial frontal gyrus, frontal pole, and inferior parietal lobule (IPL) was found during a face matching task in adults who had experienced childhood maltreatment (Jedd et al., 2015). However, the impact of recent stress on the processing of emotional expressions is still unexplored; though, acute stress has been shown to enhance

activation in the early visual cortex and FFA during the processing of emotional facial expressions (van Marle et al., 2009).

The effects of stress on the brain largely depend on their severity and timing; most studies focus on early life stress, which, due to its occurrence during sensitive periods of neural development, leaves serious and long-lasting impacts (for review, see: De Kloet, Joëls, & Holsboer, 2005; McEwen et al., 2015). Yet, there is evidence that stress experienced later in life also has lasting consequences. In this paper, we examine how early stress and recent stress affect emotional processing; this is especially interesting given that both the cumulative effects of stress and an interaction between early and recent life stress have been linked to psychopathology (McLaughlin, Conron, Koenen, & Gilman, 2010; Nederhof, Ormel, & Oldehinkel, 2014). There are two approaches which can be used to describe the effects of early and recent stress on brain activation during the processing of emotional expressions: the cumulative stress hypothesis and the match/mismatch hypothesis (Levine, 2005; Nederhof & Schmidt, 2012).

The cumulative stress hypothesis assumes that the effects of stress are additive. According to this hypothesis, prior stressors lead to increased sensitivity to stressful experiences in the future, which is why it is also referred to as the sensitization hypothesis (Hammen, Henry, & Daley, 2000). Early adversities may decrease resilience, lower the activation threshold for subsequent stressors, and enable weaker stressors to trigger the stress response (Espejo et al., 2007). Stressful experiences are associated with cognitive and affective deficits in processes associated with memory, executive functions, emotion regulation, and the processing of social and affective stimuli deficits (Pechtel & Pizzagalli, 2011). Moreover, chronic exposure to stress may lead to neurodevelopmental alterations within the structure and activity of the brain (McEwen & Gianaros, 2011).

On the other hand, the match/mismatch hypothesis assumes that early adversities promote optimal coping with similar events in the future through fostering the development of coping strategies (Santarelli et al., 2014). This approach emphasizes the importance of the interaction between early life stress and recent stress. Hence, individuals with matched environments (i.e., similar levels of early life stress and recent stress) are better off than those with mismatched environments (i.e., different levels of early and recent stress; Nederhof & Schmidt, 2012). The match/mismatch hypothesis has mainly been tested in animal studies. For example, it has been shown that stress hormones improved long-term potentiation in dentate gyrus slices extracted from mice that experienced early maternal deprivation (while doing the opposite for control mice), suggesting that adversity in early life can prepare the brain for better functioning under stress (Oomen et al., 2010). Few studies have used this approach in the context of the consequences of stress in humans (Nederhof et al., 2014; Paquola, Bennett, Hatton, Hermens, & Lagopoulos, 2017; Sandman, Davis, & Glynn, 2012).

Based on these hypotheses, it is possible to create and test two models of the influence of stress on the brain, without necessarily assessing whether or not the outcomes are adaptive. The only MRI study establishing a relationship between these two approaches regarding the impact of stress on the brain suggests that both cumulative effects and match/mismatch effects may occur in parallel, affecting different domains of brain structure and function in the resting state (Paquola et al., 2017). However, no study has looked yet into these two hypotheses in the context of task-related neural activation during emotional processing. Thus, the aim of this study was to characterize the neural activation during processing of negative facial expressions in non-clinical groups of individuals who experienced only early life stress, only recent life stress, both, or neither. This design allows the testing of both the cumulative stress model and the match/mismatch model in the context of emotional expression processing. This may help identify which of the two approaches better explains the effects of

stress on functional connectivity during the processing of emotional facial stimuli. If the match/mismatch approach were true, then the participants with matched stress exposure in childhood and adulthood would differ from those with mismatched stress. If, on the other hand, the cumulative stress hypothesis were to prove correct, then we would observe cumulative effects of both early and recent life stress. Since our investigations were performed using an emotional expression paradigm, we anticipated observing effects on the neural circuitry of structures engaged in face perception and emotional processing (i.e., the amygdala, FFA, OFA, and pSTS).

Material and Methods

Participants

A total of 85 (42 females) young adults (aged 19–25, $M = 21.64$; $SD = 1.82$) took part in the study. Of the 90 recruited participants, one was rejected due to MRI contraindication, one did not finish the task, and data from an additional three subjects were discarded due to insufficient coverage of the amygdala. Participants were selected from a community sample ($N = 503$) based on Early Life Stress Questionnaire (ELSQ) and Recent Life Changes Questionnaire (RLCQ) outcomes, as measures of stressful events. The selection of groups was based on the quartiles of the variables' distributions in the community sample. Low levels of stress in childhood and adulthood were operationalized as low scores on ELSQ and RLCQ, respectively, whereas high levels of stress were defined as high scores on these questionnaires. Exclusion criteria included the reported presence of neurological or psychiatric disorders, traumatic brain injury, addiction to alcohol, drugs, or other psychoactive substances, as well as any MRI contraindications. Participants were divided into four subgroups: the ES–/RS– group (early stress/recent stress), with low levels of stress in

both childhood and adulthood; the ES–/RS+ group, with low levels of stress in childhood and high levels of stress in adulthood; the ES+/RS– group, with high levels of stress in childhood and low levels of stress in adulthood; and the ES+/RS+ group, with high levels of stress in both childhood and adulthood. Although a relatively large community sample was recruited, the score distributions did not allow the selection of individuals who had experienced only early life stress or only late life stress, hence the stress levels in groups are somewhat asymmetrical (see Table 1). Indeed, ELSQ and RLCQ in our community sample were highly correlated ($r = .59$; $p < .001$). Previous studies suggest that early and later life stress tend to be correlated (Bosch et al., 2012; Hazel, Hammen, Brennan, & Najman, 2008; Nurius, Green, Logan-Greene, & Borja, 2015), and that it may be difficult to recruit clearly defined matched and mismatched groups (Paquola et al., 2017; Sandman et al., 2012). Groups did not differ with regards to size, sex, years of education, socioeconomic status, or age (all p 's $> .05$). The descriptive statistics are shown in Table 1. All participants provided written informed consent and were paid the equivalent of 60 euro in local currency. The procedure was approved by the local ethics committee. The study was conducted in accordance with the guidelines of the Declaration of Helsinki.

Table 1
Descriptive statistics.

	ES–/RS– group ($n = 22$) $M (SD)$	ES–/RS+ group ($n = 20$) $M (SD)$	ES+/RS– group ($n = 22$) $M (SD)$	ES+/RS+ group ($n = 21$) $M (SD)$
Females/Males	10/12	11/9	10/12	11/10
Age	21.09 (1.72)	22.05 (2.11)	21.36 (1.81)	22.10 (1.51)
Education	12.32 (2.55)	14.15 (2.64)	13.82 (2.97)	14.05 (1.60)
SES	24.97 (8.50)	26.78 (10.86)	28.75 (13.73)	26.10 (6.81)
ELSQ	.14 (.35)	1.75 (1.21)	6.32 (1.29)	9.48 (1.47)
RLCQ	.77 (1.23)	18.85 (2.68)	7.18 (3.25)	26.52 (6.23)

ELSQ–Early Life Stress Questionnaire; ES–early stress; RLCQ–Recent Life Changes Questionnaire; RS–recent stress; SES–socioeconomic status.

Assessment

Early life stress was assessed with the Early Life Stress Questionnaire (ELSQ; Cohen et al., 2006; Sokołowski & Dragan, 2017). It measures exposure to 19 stressful events, including emotional, sexual, and physical abuse, violence, negligence, parental divorce, surgery, parental death, separation, etc. Participants report whether they experienced any of these events before the age of 12. Reliability was assessed by estimating internal consistency using Cronbach's α , which was $\alpha = .85$ in our sample.

The Recent Life Changes Questionnaire (RLCQ; Rahe, 1975) was used to measure levels of stress in adulthood. Participants were asked whether they had experienced stressful events in the previous 24 months. Its Cronbach's α in our sample was .94.

The Socioeconomic Status Index was computed based on the Scale of Material Remuneration (Domański, Sawiński, & Słomczynski, 2009), which covers average income related to the participants' profession.

Experimental Task

Participants were tested in an fMRI scanner during a single session. Subjects were familiarized with the scanner and the experimental task procedure in a mock scanner with stimuli different from those used in the experiment. Participants performed three tasks as part of a larger project, and the data from the face-matching task are presented here. A set of 150 color face images of 30 individuals was used. The stimuli were taken from a standardized database (Warsaw Set of Emotional Facial Expression Pictures; Olszanowski et al., 2015). Pictures displayed different emotions (fear, anger, disgust, and happiness) as well as neutral faces.

The face-matching task was adapted with adjustments from previous studies on emotion recognition and processing (Åhs et al., 2014; Hariri, Bookheimer, & Mazziotta,

2000). Two conditions were used to measure neural response to facial expressions: emotional and control. During each trial, three faces were presented on the screen—one at the top and two at the bottom. In the emotional condition, participants were asked to match the emotional expression—i.e., to select the face on the bottom that expressed the same emotion as the target face on top (Figure 1). In the control condition, all faces were neutral and subjects were instructed to select which of the bottom pictures was the same as the target face on top. Although geometric shapes are usually used as a sensorimotor control (Åhs et al., 2014; Demers, Drabant Conley, Bogdan, & Hariri, 2016; Goetz et al., 2014), we decided to use different stimuli in the control condition. Neutral faces were chosen to subtract the activation related to face perception in predefined contrasts, leaving only activation related to the processing of emotional expressions.

The stimuli were presented in a block design with two conditions: emotional and neutral. Each block started with an instruction slide (4 s) followed by six trials (three female and three male face trios, presented randomly). Images were presented for 4 s in a randomized fashion for all conditions, with a variable inter-stimulus interval of 1.5 s to 3 s. Each of the two runs consisted of four experimental (emotional) blocks (fear, anger, disgust, and happiness; displayed randomly) and four control blocks, presented alternately. Stimuli were presented against a grey background using the Presentation software (Neurobehavioral Systems, Inc., Berkeley, CA). Accuracy and response time were registered as behavioral measures.

Figure 1. Face-matching task—emotional (left) and control (right) conditions. The emotional and control blocks were presented in an alternating order; six trials of the same emotional condition within each block were used.

MRI Data Acquisition and Preprocessing

Whole-brain functional and structural images were acquired using a 3T MRI scanner (Trio TIM, Siemens, Germany) equipped with a 32-channel head coil. First, a localizer and high-resolution T1-weighted images were obtained. TR/TI/TE = 2530/1100/3.32 ms; flip angle = 7°; PAT factor = 2; FoV = 256 mm; voxel dimensions = 1 mm isotropic; 256×256 voxel resolution. Functional images were acquired using a T2-weighted, gradient-echo echo planar imaging (EPI) pulse sequence during two functional runs. For each experimental run, 176 whole-brain volumes were recorded with the following parameters: TR/TE=2000/30 ms; flip angle=90°; 64×64 matrix size; FoV = 224 mm; 3.5×3.5 mm vox size; 35 slices (interleaved ascending); 3.5 mm slice thickness.

Analyses were performed using Statistical Parametric Mapping (SPM12; Wellcome Department of Cognitive Neurology, London, UK), implemented in MATLAB (2018, The Math-Works Inc., Natick, MA, USA). Images were spatially realigned, slice-time corrected (to the middle slice), co-registered to the first functional image, segmented, normalized to the standard Montreal Neurological Institute (MNI) template, and spatial smoothed with an 8 mm isotropic Gaussian kernel.

First-level Analysis

Data from two experimental runs were modeled with a general linear model (GLM) for each subject for the first-level analysis. Vectors representing all task conditions and instructions were added to the model: (a) fearful faces; (b) angry faces; (c) disgusted faces; (d) happy faces; (e) neutral faces; and (f) instructions. Each regressor was convolved with a canonical hemodynamic response function. The model included regressors of no interest to account for head motion. Additionally, the Artifact Detection Tool (ART) toolbox was used to determine motion-affected volumes exceeding 2 mm or 0.05 rad movement thresholds (which were excluded from analyses).

Second-level Analysis

Single-subject contrasts (fearful, angry, and disgusted faces > neutral faces, i.e., a $[-1 \ -1 \ 1 \ 1 \ 3]$ contrast) underwent second-level analyses. To test the match/mismatch hypothesis, a 2x2 full factorial model was used with early and recent life stress on two levels (high and low) at the group level. Main effects of early life stress, recent stress, and their interaction were analyzed. The match > mismatch contrast corresponded to the $[1 \ -1 \ -1 \ 1]$ group contrast; the mismatch > match contrast corresponded to the $[-1 \ 1 \ 1 \ -1]$ group contrast. To test the cumulative stress hypothesis, the cumulative stress index was used in a regression analysis. This index was computed as a sum of standardized early and recent stress scores. Family-wise error (FWE < .05) was used to control for multiple comparisons in whole-brain analysis.

gPPI Analysis

The CONN functional connectivity toolbox (v.18a; <http://www.nitrc.org/projects/conn>) with denoising and a false discovery rate (FDR < .05)

correction was used to conduct the functional connectivity analysis. All regressors of interest and no interest were entered into a gPPI model, and a group-level seed-based connectivity analysis was performed for the negative emotional expressions > neutral faces contrast. Positive connectivity indicates positive Fisher transformed correlation coefficient values between BOLD signals in the seed and a cluster (i.e., the two structures are likely to be active at the same time), while negative connectivity refers to negative correlation (sometimes also called anticorrelation).

The bilateral amygdala, FFA, OFA, and pSTS were chosen as seed regions based on their involvement in the processing of facial expressions: the amygdala is a crucial structure involved in emotional processing (Phelps & LeDoux, 2005; van Harmelen et al., 2013); the FFA (Ganel et al., 2005; Vuilleumier, Armony, Driver, & Dolan, 2001; Winston, O'Doherty, & Dolan, 2003; Xu & Biederman, 2010) and pSTS are involved in the processing of emotional facial expressions (Engell & Haxby, 2007; Fox, Moon, Iaria, & Barton, 2009; Ganel et al., 2005; Pitcher, Duchaine, & Walsh, 2014); the OFA was selected because of its involvement in face processing (Duchaine & Yovel, 2015; Haxby et al., 2000; Nagy, Greenlee, & Kovács, 2012).

Seeds were defined prior to data analysis. The amygdala has a clearly determined anatomical location, hence it was defined using the Automated Anatomical Labeling (AAL) atlas implemented in the Wake Forest University Pickatlas (WFU_PickAtlas 3.0.5). Because a face area localizer task (i.e., faces vs non-faces contrast) was not used to localize the face-specific regions in our study, Activation Likelihood Estimate (ALE) meta-analysis was conducted to localize the FFA, OFA, and pSTS. They were localized based on loci from 30 recent studies concerning face processing (see supplementary material for the list of loci). Talairach coordinates were transformed to MNI coordinates using GingerALE (v.2.3.6; <http://www.brainmap.org/ale/>). All loci were entered into the GingerALE analysis with FDR

$< .05$. The MarsBar toolbox was used to build region of interest (ROI) clusters. Spheres with 6 mm radii were built around the peak activation reported by ALE meta-analysis. The following ROIs (coordinates in MNI space) were defined: left FFA (-41 -52 -19), right FFA (42 -50 -20), left OFA (-39 -78 -10), right OFA (42 -77 -10), left pSTS (-52 -57 12), and right pSTS (53 -50 10). The Harvard-Oxford atlas was used to label the results.

Results

Behavioral Results

In order to examine the effects of early life stress and recent stress on reaction time (RT) and accuracy, two-way ANOVAs were performed for each condition. There was no main effect of early life stress, recent stress, nor their interaction on RT or accuracy in all task conditions—that is, groups did not differ in terms of RT or accuracy regardless of the stimuli. Moreover, there seemed to be a ceiling effect on the accuracy (see supplementary material).

Across all participants, a repeated measures ANOVA determined that RT differed between task conditions ($F_{3, 252} = 148.92$; $p < .001$; $\eta_p^2 = .64$). Post-hoc tests with Bonferroni correction revealed the longest RT in the anger condition and the shortest RT in the neutral condition, compared to all other conditions (all p 's $< .001$).

Whole-brain Analyses

Whole-brain analyses were conducted for the emotional expressions vs. neutral faces contrast. First, analyses were performed across all participants (see supplementary material). This revealed activations ($p < .001$ unc.; FWE $< .05$) mainly in the inferior and middle frontal gyri (IFG and MFG), fusiform gyrus (FuG), and inferior occipital gyrus (IOG). There was deactivation in the anterior and posterior cingulate cortex (ACC and PCC), middle occipital

gyrus (MOG), and superior frontal gyrus (SFG). Second, whole-brain analyses were performed for the match/mismatch model. Contrary to our prediction, there were no significant main effects of early and late life stress, nor was there an interaction, which indicates that there were no differences in whole-brain activation between the matched and mismatched groups. Third, the cumulative model was verified, but revealed no significant cumulative effects of stress on whole-brain activation.

Functional Connectivity

Match/mismatch hypothesis.

Results for the matched group vs. mismatched group contrasts of seed-based connectivity for given seeds are presented in Table 2 and Figure 2 (see supplementary material for main effects of early life stress and recent stress).

Table 2.

Interaction between early life stress and recent stress for functional connectivity during the face-matching task.

Seed	Contrast and brain region		k	P (FDR)	β	x	y	z
Left Amyg	Mismatch > match							
	sLOC	R	589	<.001	.25	36	-80	22
	Thalamus	R	143	.004	.25	6	-24	2
Right Amyg	Mismatch > match							
	ACC	R	383	<.001	.25	12	22	28
	OFC/Insula	R	326	<.001	.23	38	22	-12
	PAC/ACC	L	115	.008	.23	-8	18	36
Left FFA	Match > mismatch							
	IFG	L	419	<.001	.25	-52	22	4
	Mismatch > match							
	TP	R	91	.035	.25	44	12	-18
Right FFA	Match > mismatch							
	Cerebellum	L	127	.016	.21	-8	-78	-24
	Mismatch > match							
	Amygdala/hippocampus	R	473	<.001	.24	26	-2	-24
	Insula/TP	R	181	.001	.24	36	2	-16
	Amygdala	L	112	.010	.23	-26	4	-20
	ACC	L	88	.021	.26	-6	20	18

Left OFA	Match > mismatch							
	Cerebellum	L	191	.001	.23	-30	-72	-24
	Cerebellum	R	132	.003	.25	28	-68	-30
	Cerebellum	R	93	.013	.24	48	-46	-44
	Mismatch > match							
	Insula/OFC	R	97	.034	.26	30	12	-18
Right OFA	Mismatch > match							
	Insula/OFC	R	196	.001	.24	44	12	-14
	LgG	R	195	.001	.25	44	-44	-2
	Thalamus/hippocampus	L	141	.003	.25	-20	-28	-2
	Hippocampus/amygdala	R	76	.033	.23	16	-12	-16
Left pSTS	Match > mismatch							
	IFG	R	131	.006	.24	58	12	14

Regions are defined by MNI coordinates; L–left hemisphere; R– right hemisphere. ACC–anterior cingulate cortex; Amyg–amygdala; FFA–fusiform face area; IFG–inferior frontal gyrus; LgG–lingual gyrus; OFA–occipital face area; OFC–orbitofrontal cortex; PAC–paracingulate gyrus; pSTS–posterior superior temporal sulcus; sLOC–superior lateral occipital cortex.

Below are the results for post-hoc tests for the groups of connections in which between-group differences were significant, organized by seeds.

Left amygdala seed.

A difference between the matched and the mismatched group was found for functional connectivity between the left amygdala and right superior lateral occipital cortex (sLOC). The matched group exhibited negative connectivity ($\beta = -.10$; $p < .001$), while the mismatched group exhibited positive connectivity ($\beta = .15$; $p < .001$). The matched group had negative connectivity between the left amygdala and right thalamus ($\beta = -.08$; $p < .001$), while the mismatched group displayed positive connectivity ($\beta = .17$; $p < .001$).

Right amygdala seed.

The right amygdala was negatively coupled with the right ACC ($\beta = -.14$; $p < .001$) in the matched group, while it was positively coupled in the mismatched group ($\beta = .10$; $p < .001$). The matched group had negative connectivity between the right amygdala and right OFC ($\beta = -.08$; $p < .001$), while the mismatched group showed positive connectivity ($\beta = .15$;

$p < .001$). The matched group exhibited negative connectivity between the right amygdala and left paracingulate gyrus (PAC)/ACC ($\beta = -.10$; $p < .001$), while the mismatched group displayed positive connectivity ($\beta = 0.13$; $p < .001$).

Left FFA seed.

The matched group exhibited positive connectivity between the left FFA and left IFG ($\beta = .23$; $p < .001$), while the mismatched group had negative connectivity ($\beta = -.03$; $p < .001$). The matched group had negative connectivity with the left temporal pole ($\beta = -.06$; $p < .001$), while the mismatched group had positive connectivity ($\beta = .19$; $p < .001$).

Right FFA seed.

The matched group exhibited negative connectivity between the right FFA and right ($\beta = -.13$; $p < .001$) and left ($\beta = -.08$; $p < .001$) amygdalae, while the mismatched group showed positive connectivity with the right ($\beta = .11$; $p < .001$) and left ($\beta = .12$; $p < .001$) amygdalae. The matched group had negative connectivity with the right insula ($\beta = -.08$; $p < .001$), while the mismatched group had positive connectivity ($\beta = .16$; $p < .001$). The matched group exhibited negative connectivity with the left ACC ($\beta = -.15$; $p < .001$), while the mismatched group showed positive connectivity ($\beta = .11$; $p < .001$). The matched group had positive connectivity with the left cerebellum ($\beta = .08$; $p < .001$), while the mismatched group had negative connectivity ($\beta = -.13$; $p < .001$).

Left OFA seed.

The matched group exhibited positive connectivity between the left FFA and left ($\beta = .16$; $p < .001$) and right (peak activation [28 -68 -30], $\beta = .16$; $p < .001$; peak activation [48 -46 -44], $\beta = .11$; $p < .001$) cerebellums, while the mismatched group displayed negative connectivity with the left ($\beta = -.07$; $p < .001$) and right (peak activation [28 -68 -30], $\beta = -.09$; $p < .001$; peak activation [48 -46 -44], $\beta = -.13$; $p < .001$) cerebellums. The matched group

had negative connectivity between the left OFA and left insula/OFC ($\beta = -.10$; $p < .001$), while the mismatched group had positive connectivity ($\beta = .16$; $p < .001$).

Right OFA seed.

An interaction between early life and recent stress was observed for connectivity between right OFA and right OFC/insula. The matched group had negative connectivity ($\beta = -.08$; $p < .001$), while the mismatched group had positive connectivity ($\beta = .16$; $p < .001$). The matched group had negative connectivity with the right lingual gyrus ($\beta = -.17$; $p < .001$), while the mismatched group had positive connectivity ($\beta = .07$; $p < .001$). The matched group exhibited negative connectivity with the left thalamus ($\beta = -.13$; $p < .001$), while the mismatched group displayed positive connectivity ($\beta = .12$; $p < .001$). The matched group had negative connectivity with the left hippocampus/amygdala ($\beta = -.08$; $p < .001$), while the mismatched group displayed positive connectivity ($\beta = .15$; $p < .001$).

Left pSTS seed.

There was an interaction between early life and recent stress related to connectivity between the left pSTS and right IFG. The matched group exhibited positive connectivity ($\beta = .20$; $p < .001$), while the mismatched group exhibited negative connectivity ($\beta = -.05$; $p < .001$).

Figure 2. Seed-based functional connectivity during face-matching for the match/mismatch model. Arrows in red indicate stronger connectivity in the matched group and arrows in green indicate stronger connectivity in the mismatched group. Beta values, i.e., average differences in Fisher-transformed correlation coefficients (connectivity strength) between the two groups, are displayed on the arrows. (A) amygdala seeds; (B) FFA seeds; (C) OFA seeds; (D) pSTS seed. Amyg–amygdala; ACC–anterior cingulate cortex; Cb–cerebellum; FFA–fusiform face area; Hipp–hippocampus; IFG–inferior frontal gyrus; LgG–lingual gyrus; OFA–occipital face area; OFC–orbitofrontal cortex; pSTS–posterior superior temporal sulcus; sLOC–superior lateral occipital cortex; TP–temporal pole.

Cumulative stress hypothesis.

A seed-based connectivity analysis was used to examine neural circuitry related to cumulative stress. The results are reported in Table 3 and Figure 3.

Amygdala seed.

No functional connectivity was observed for the amygdala seeds.

FFA seed.

There was a negative relationship between cumulative stress and the strength of functional connectivity between the left FFA and left Heschl's gyrus ($\beta = -.03$) as well as the sLOC ($\beta = -.03$). Cumulative stress was negatively related to connectivity between the right FFA and right sLOC ($\beta = -.04$).

OFA seed.

Cumulative stress was negatively related to connectivity between the left OFA and left occipital fusiform gyrus ($\beta = -.03$). Cumulative stress was negatively related to connectivity between the right OFA and right precentral gyrus ($\beta = -.03$), left precentral gyrus ($\beta = -.04$), left somatosensory region ($\beta = -.03$), amygdala ($\beta = -.03$), MTG ($\beta = -.04$), and IFG ($\beta = -.03$).

pSTS seed.

Cumulative stress was negatively related to connectivity between the left pSTS and left ACC ($\beta = -.03$), right PCC ($\beta = -.03$), right precuneus ($\beta = -.03$), and left Heschl's gyrus ($\beta = -.04$).

Table 3.

Regression analysis for functional connectivity during the face-matching task.

Seed region	Contrast and brain region		k	p (FDR)	β	x	y	z
Left FFA	Negative correlation							
	Heschl's gyrus	L	109	.019	-.03	-32	-28	10
	sLOC	R	94	.019	-.03	30	-62	56
Right FFA	Negative correlation							
	sLOC	R	182	.001	-.04	26	-68	32
Left OFA	Negative correlation							
	OFusG	L	124	.015	-.03	-28	-84	-20
Right OFA	Negative correlation							
	MTG/PT	L	219	.001	-.04	-44	-40	10
	PrG/PoG	R	149	.003	-.03	18	-26	60
	Amygdala	L	111	.009	-.03	-20	-6	-20
	IFG	L	109	.009	-.03	-46	10	18
	PrG	L	103	.009	-.04	-50	-4	52
	PrG/PoG	L	73	.030	-.03	-18	-32	64
Left pSTS	Negative correlation							
	ACC/FP	L	723	<.001	-.03	-6	28	-4
	PCun	R	541	<.001	-.03	24	-60	12
	PCC	R	431	<.001	-.03	6	-38	24
	Heschl's gyrus	L	421	<.001	-.04	-40	-26	10

Regions are defined by MNI coordinates; L–left hemisphere; R–right hemisphere. ACC–anterior cingulate cortex; FFA–fusiform face area; FP–frontal pole; IFG–inferior frontal gyrus; MTG–middle temporal gyrus; OFA–occipital face area; OFusG–occipital fusiform gyrus; PCC–posterior cingulate cortex; PCun–precuneus; PoG–postcentral gyrus; PrG–precentral gyrus; pSTS–posterior superior temporal sulcus; PT–planum temporale; sLOC–superior lateral occipital cortex.

Figure 3. Seed-based functional connectivity during the face-matching task for the cumulative stress model: (A) FFA seeds; (B) OFA seeds; (C) pSTS seed. Beta values, i.e., expected increases in Fisher-transformed correlation coefficients (connectivity strength), for each unit-increase in cumulative stress levels are displayed on the arrows. Amyg—amygdala; ACC—anterior cingulate cortex; FFA—fusiform face area; FP—frontal pole; Heschl—Heschl's gyrus; IFG—inferior frontal gyrus; MTG—middle temporal gyrus; OFA—occipital face area; OFusG—occipital fusiform gyrus; PCC—posterior cingulate cortex; PCun—precuneus; PoG—postcentral gyrus; PrG—precentral gyrus; pSTS—posterior superior temporal sulcus; PT—planum temporale; sLOC—superior lateral occipital cortex.

Discussion

The present study investigated the impact of stress on brain circuitry related to the processing of negative emotional expressions. We examined two models of the consequences of stress based on the match/mismatch and cumulative stress hypotheses: the first hypothesis posits a beneficial effect associated with levels of stress in early and recent life being similar, even if these levels are high; the second suggests that stress has an additive negative effect.

Both of these effects are assumed to have some underlying physiological mechanisms related to the HPA axis and the brain (De Kloet et al., 2005; McEwen et al., 2015). Previous studies have shown that, although the two stress consequence hypotheses seem mutually exclusive, models of stress impact on the brain structure and function based on these hypotheses can, in fact, act in parallel. Depending on the structure or process, stress may have an impact that is better explained by the cumulative stress model or the match/mismatch model (Paquola et al., 2017; Zalosnik, Pollano, Trujillo, Suárez, & Durando, 2014). Thus, when talking about the neural correlates of experienced stress, it may be that one shouldn't contrast these two models in terms of adaptiveness, but rather in terms of the different ways in which levels of stress throughout life can influence different structures and circuits in the brain. Here, we compare results for these two models in order to discuss potential differences in the impact of cumulative and matched/mismatched levels of stress on brain functioning during processing of emotional facial expressions.

The behavioral results did not show any differences between the matched and mismatched groups in terms of accuracy and reaction time during performance of the face-matching task. This was not surprising, as the task was relatively easy and the presentation time of the stimuli was long enough to facilitate correct answers. Hence, the results suggest the existence of a ceiling effect. Whole-brain fMRI analysis of the negative emotional expressions and neutral faces contrast for all participants revealed activations in the visual cortex, prefrontal cortex, and areas engaged in face perception (i.e., the FFA, OFA, and pSTS), which justifies the choice of these regions as seeds. Surprisingly, we did not observe activation of the amygdala. Nevertheless, these results are largely consistent with a model of brain activity relating face perception and expression processing (Duchaine & Yovel, 2015; Haxby et al., 2000).

We did not observe differences in whole-brain activation between the matched and mismatched groups during the processing of negative emotional expressions, nor did we observe a relationship between the strength of activation and cumulative stress. This is surprising; however, there are some factors which could have led to such results, including the characteristics of both the sample and the stimuli. First, we used an overall index of negative experiences without distinguishing between types of negative life events—it has previously been shown that different stressors may have distinct impacts on functioning (Dragan, 2018; McLaughlin, McLaughlin, & Sheridan, 2016). The intensity of emotional stimuli is also related to the brain response to these stimuli (Kensinger & Schacter, 2006; Silvers, Weber, Wager, & Ochsner, 2015). Given that emotional faces are less arousing than, for example, images depicting dramatic scenes or traumatic events (e.g., those that can be found in the International Affective Picture System; Alpers, Adolph, & Pauli, 2011; Britton, Taylor, Sudheimer, & Liberzon, 2006), it is possible that these stimuli did not pass the threshold of intensity for observation of a group difference. The choice of moderately arousing stimuli in our study could also be part of the reason that we did not observe group differences in whole-brain activation, and would similarly explain the lack of amygdala activation across all participants.

As in previous studies, our study also found that both the interaction between early and recent life stress as well as cumulative stress levels were related to differences in functional connectivity in the brain during processing of negative emotional expressions. Interestingly, only the match/mismatch model, and not the cumulative model, revealed differences in the functional connectivity of the amygdala seeds. All significant functional connectivity per contrast (all connections were stronger for the mismatched group) involved structures that have previously been associated with the processing of emotional stimuli (Fusar-Poli et al., 2009; Kohn et al., 2014). Results for the left amygdala were consistent with

the amygdala receiving input from the thalamus and the visual cortex. Connections from the right amygdala targeted mediofrontal regions, which are involved more in the emotional aspects of facial expression processing. Interestingly, amygdala–thalamus connections are associated with a subcortical pathway of fear conditioning and allow one to quickly respond to emotional stimuli (Phelps & LeDoux, 2005). Thus, at least in our sample, the match/mismatch model did explain the impact of stress on amygdalar functional connectivity during emotional face processing, while the cumulative stress model failed to do so.

Seeds located in the left and right FFA yielded some significant results for both models. In the match/mismatch model, this time the majority of stronger connections were observed in the mismatched group rather than the matched group. More differences in functional connectivity with other regions during emotional face processing were found for the right FFA than left FFA, which could stem from the well-known asymmetry in face processing in most right-handed individuals (favoring the right hemisphere; Brancucci, Lucci, Mazzatenta, & Tommasi, 2009). The connections from the right FFA that were stronger in the mismatched group were found in structures of the limbic system that are involved in processing emotional aspects of faces (Duchaine & Yovel, 2015). The stronger connection between the right FFA and the left cerebellum in the matched group seems harder to interpret. It could be that stronger connectivity with the cerebellum is associated with more automatized processing of emotional stimuli—the cerebellum plays a role in coordinating shifts of attention, aids information retrieval, and plays a role in automatization of cortical processing (Sokolov, Miall, & Ivry, 2017). The matched group also exhibited a stronger connection between the left FFA and IFG—a region involved in processing the semantic aspects of faces (Zhen, Fang, & Liu, 2013). In turn, the cumulative stress hypothesis explained differences in connectivity to regions associated with lower levels of visual processing, with higher levels of stress being associated with stronger anticorrelations between bilateral FFAs and sLOC— a

structure known to have a role in object recognition (Pitcher, Duchaine, Walsh, Yovel, & Kanwisher, 2011).

Differences in strengths of connections from the left and right OFAs also presented varying patterns depending on the model. Here, again, more results were observed for the structure in the right hemisphere, which, again, could be because this structure is also characterized by functional asymmetry (Pitcher, Walsh, Yovel, & Duchaine, 2007). The OFAs' role in face perception focuses on recognizing facial features (Pitcher, Walsh, & Duchaine, 2011), which is a step that precedes processing in the FFA (Duchaine & Yovel, 2015; Liu, Harris, & Kanwisher, 2010). The mismatched group exhibited stronger functional connections than the matched group between the right OFA and regions of the limbic system involved in emotion processing, as well as the lingual gyrus, which is involved in complex visual processing. Here again, the matched group exhibited stronger functional connectivity between the left OFA and several clusters in the cerebellum, which may have a similar explanation to that proposed with regards to FFA–cerebellum connectivity. Cumulative stress explained more negative connectivity between the right OFA and the amygdala, posterior MTG, which is involved in social cognition (interpreting others' intentions; Mar, 2011), and the IFG, which plays a role in emotion regulation (Kohn et al., 2014). Several significant clusters in the left and right precentral/postcentral gyri are an interesting result. These regions are usually not mentioned in the context of emotional face processing, but some evidence suggests that somatosensory regions are also important for recognizing emotions from facial expressions through generating somatosensory representations of how the other individual feels (Adolphs, Damasio, Tranel, Cooper, & Damasio, 2000; Kragel & LaBar, 2016). It may be that the match/mismatch model and the cumulative model explain connections between the OFA and structures responsible for different aspects of emotional processing. Alternatively, it may be that the somatosensory regions are indeed not crucial for emotion processing and the

increasingly negative correlations represent their higher disengagement in individuals who have experienced more stress and hence focus more attention on emotional processing.

The functional connectivity of pSTS also exhibited different patterns for the two models. The matched group exhibited stronger connections between the left pSTS and the IFG, which is in line with the model of connections between face-selective areas (Duchaine & Yovel, 2015). On the other hand, in the cumulative model, a negative correlation was found between the activity of the left pSTS and the activity of some of the areas in the default mode network, the activity of which is normally anticorrelated with goal-oriented actions (Uddin, Kelly, Biswal, Castellanos, & Milham, 2009). This may mean that people who have experienced higher cumulative stress show a greater attentional shift towards the performance of the facial expression processing task.

In summary, in the match/mismatch model, the mismatched group exhibited stronger connectivity between the seed regions and other regions involved in face processing and areas more traditionally associated with emotion processing, i.e., the amygdala and areas which largely correspond to the limbic system. On the other hand, the matched group exhibited stronger functional connectivity of face-selective areas with the cerebellum, which is engaged in reinforcement learning processes (Swain, Kerr, & Thompson, 2011). It may indicate that the matched group is characterized by more effective learning of the emotional value of encountered stimuli. Together, this may mean that emotional expression processing requires the stronger engagement of areas typically associated with emotion processing in the mismatched group, while it is more automatic in the matched group. This interpretation would indicate that the matched group has an advantage over the mismatched group in emotion expression processing, which would be in line with the idea behind the match/mismatch hypothesis—that matched stress facilitates the action of more adaptive mechanisms that increase the fitness of an individual under aversive conditions (Nederhof & Schmidt, 2012).

In turn, the negative correlations in the cumulative stress model may suggest that individuals who have experienced more overall stress devote more resources to emotional expression processing—their attention is more selectively focused on the task, which is reflected by suppressed activity in regions that are not crucial for these processes. This may influence the processing of external salient information, which takes the form of attentional bias towards threats (Pine et al., 2005). This altered processing of emotional stimuli may lead to the development of stress-related psychopathology (Jenness, Hankin, Young, & Smolen, 2016). Numerous studies have shown that stress-related disorders are associated with attentional bias towards emotional stimuli, which is evident especially in depression and anxiety disorders (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007; Beck, 2008).

However, the proposed interpretations of the results should be considered with caution, as stress-related alterations in brain activity when performing tasks related to emotion processing can be explained in two ways: as a sign of a deficit or of compensation. Weaker activity or connections could indicate either ineffective involvement of the brain structures in question, or conversely, more efficient performance (Etkin, Prater, Hoefft, Menon, & Schatzberg, 2010; Phillips, Ladouceur, & Drevets, 2008). On the other hand, higher activations or stronger connections could indicate more efficient processing, but could also mean that more cognitive and neural resources are needed to effectively perform the task (Etkin & Schatzberg, 2011; Reuter-Lorenz & Cappell, 2008).

The fact that both early life and recent stress as well as their interaction were examined is a strength of this study. To our knowledge, there has been no previous attempt to simultaneously explore models based on both the cumulative stress hypothesis and the match/mismatch hypothesis in the context of processing negative emotional expressions. Another strength is the use of neutral faces as the control condition, rather than shapes or

objects. We were able to subtract neuronal activation related to processing emotional expressions, controlling the activation relating to face perception *per se*.

However, we would like to also acknowledge some limitations of this study. First, resilience wasn't measured in our study. Future research should include resilience as it could potentially elucidate the mechanisms behind match and mismatch effects and shed light on the levels of adaptation of different groups. Our study also does not examine particular stressors separately; it is known that distinct adverse events (such as physical abuse, a death in the family, or being bullied) may have at least partially different consequences (McLaughlin et al., 2016). These situations are characterized by differing quantities and qualities of deprivation and threat. It is also possible to distinguish between stressors related to personal experience and those related to other people (Dragan, 2018; Palgi, Shrira, Ben-Ezra, Shiovitz-Ezra, & Ayalon, 2012; Shmotkin & Litwin, 2009). Our study also did not differentiate between brief and chronic stress—both animal and human studies show that whether one develops psychopathology or resilience as a result of early stress may depend on the levels and duration of that stress (Franklin, Saab, & Mansuy, 2012). Therefore, future studies on emotional processing should investigate how different adversities affect brain activations in the context of emotion processing.

To conclude, we found that both the interaction between early life stress and recent life stress as well as cumulative stress levels were related to alterations in different neural circuits during emotion processing, observed as altered functional connectivity. Therefore, this research adds to the growing body of literature suggesting that models based on both the cumulative stress hypothesis and the match/mismatch hypothesis are useful for explaining the effects of stress on humans. Further studies are needed to explore the impacts of different kinds of stressors on functional connectivity during emotion processing and to determine

whether the observed alterations in neural circuits are beneficial or maladaptive in the context of emotion processing.

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References

- Adolphs, R., Damasio, H., Tranel, D., Cooper, G., & Damasio, A. R. (2000). A Role for Somatosensory Cortices in the Visual Recognition of Emotion as Revealed by Three-Dimensional Lesion Mapping. *Journal of Neuroscience*, *20*(7), 2683–2690.
doi:10.1523/jneurosci.20-07-02683.2000
- Åhs, F., Engman, J., Persson, J., Larsson, E.-M., Wikström, J., Kumlien, E., & Fredrikson, M. (2014). Medial temporal lobe resection attenuates superior temporal sulcus response to

- faces. *Neuropsychologia*, 61, 291–298. doi:10.1016/j.neuropsychologia.2014.06.030
- Alpers, G. W., Adolph, D., & Pauli, P. (2011). Emotional scenes and facial expressions elicit different psychophysiological responses. *International Journal of Psychophysiology*, 80(3), 173–181. doi:10.1016/j.ijpsycho.2011.01.010
- Bar-Haim, Y., Lamy, D., Pergamin, L., Bakermans-Kranenburg, M. J., & van IJzendoorn, M. H. (2007). Threat-related attentional bias in anxious and nonanxious individuals: A meta-analytic study. *Psychological Bulletin*, 133(1), 1–24. doi:10.1037/0033-2909.133.1.1
- Beck, A. T. (2008). The Evolution of the Cognitive Model of Depression and Its Neurobiological Correlates. *American Journal of Psychiatry*, 165(8), 969–977. doi:10.1176/appi.ajp.2008.08050721
- Bernstein, M., & Yovel, G. (2015). Two neural pathways of face processing: A critical evaluation of current models. *Neuroscience & Biobehavioral Reviews*, 55, 536–546. doi:10.1016/j.neubiorev.2015.06.010
- Bosch, N. M., Riese, H., Reijneveld, S. A., Bakker, M. P., Verhulst, F. C., Ormel, J., & Oldehinkel, A. J. (2012). Timing matters: Long term effects of adversities from prenatal period up to adolescence on adolescents' cortisol stress response. The TRAILS study. *Psychoneuroendocrinology*, 37(9), 1439–1447. doi:10.1016/j.psyneuen.2012.01.013
- Brancucci, A., Lucci, G., Mazzatenta, A., & Tommasi, L. (2009). Asymmetries of the human social brain in the visual, auditory and chemical modalities. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, 364(1519), 895–914. doi:10.1098/rstb.2008.0279
- Britton, J. C., Taylor, S. F., Sudheimer, K. D., & Liberzon, I. (2006). Facial expressions and complex IAPS pictures: Common and differential networks. *NeuroImage*, 31(2), 906–919. doi:10.1016/j.neuroimage.2005.12.050

- Campos, J. J., Frankel, C. B., & Camras, L. (2004). On the Nature of Emotion Regulation. *Child Development*, 75(2), 377–394. doi:10.1111/j.1467-8624.2004.00681.x
- Cohen, R. A., Hitsman, B. L., Paul, R. H., McCaffery, J., Stroud, L., Sweet, L., ... Gordon, E. (2006). Early Life Stress and Adult Emotional Experience: An International Perspective. *The International Journal of Psychiatry in Medicine*, 36(1), 35–52. doi:10.2190/5R62-9PQY-0NEL-TLPA
- Dannlowski, U., Stuhrmann, A., Beutelmann, V., Zwanzger, P., Lenzen, T., Grotegerd, D., ... Kugel, H. (2012). Limbic Scars: Long-Term Consequences of Childhood Maltreatment Revealed by Functional and Structural Magnetic Resonance Imaging. *Biological Psychiatry*, 71(4), 286–293. doi:10.1016/j.biopsych.2011.10.021
- De Kloet, E. R., Joëls, M., & Holsboer, F. (2005). Stress and the brain: From adaptation to disease. *Nature Reviews Neuroscience*, 6(6), 463–475. doi:10.1038/nrn1683
- Demers, C. H., Drabant Conley, E., Bogdan, R., & Hariri, A. R. (2016). Interactions Between Anandamide and Corticotropin-Releasing Factor Signaling Modulate Human Amygdala Function and Risk for Anxiety Disorders: An Imaging Genetics Strategy for Modeling Molecular Interactions. *Biological Psychiatry*, 80(5), 356–362. doi:10.1016/j.biopsych.2015.12.021
- Domański, H., Sawiński, Z., & Słomczynski, K. M. (2009). *Sociological Tools Measuring Occupations: New Classification and Scales*. Warsaw: IFIS Publishers.
- Dragan, M. (2018). Adverse experiences, emotional regulation difficulties and psychopathology in a sample of young women: Model of associations and results of cluster and discriminant function analysis. *European Journal of Trauma & Dissociation*. doi:10.1016/j.ejtd.2018.12.001
- Duchaine, B., & Yovel, G. (2015). A Revised Neural Framework for Face Processing. *Annual Review of Vision Science*, 1, 393–416. doi:10.1146/annurev-vision-082114-035518

- Engell, A. D., & Haxby, J. V. (2007). Facial expression and gaze-direction in human superior temporal sulcus. *Neuropsychologia*, 45(14), 3234–3241. doi:10.1016/j.neuropsychologia.2007.06.022
- Espejo, E. P., Hammen, C. L., Connolly, N. P., Brennan, P. A., Najman, J. M., & Bor, W. (2007). Stress Sensitization and Adolescent Depressive Severity as a Function of Childhood Adversity: A Link to Anxiety Disorders. *Journal of Abnormal Child Psychology*, 35(2), 287–299. doi:10.1007/s10802-006-9090-3
- Etkin, A., Prater, K. E., Hoeft, F., Menon, V., & Schatzberg, A. F. (2010). Failure of Anterior Cingulate Activation and Connectivity With the Amygdala During Implicit Regulation of Emotional Processing in Generalized Anxiety Disorder. *American Journal of Psychiatry*, 167(5), 545–554. doi:10.1176/appi.ajp.2009.09070931
- Etkin, A., & Schatzberg, A. F. (2011). Common Abnormalities and Disorder-Specific Compensation During Implicit Regulation of Emotional Processing in Generalized Anxiety and Major Depressive Disorders. *American Journal of Psychiatry*, 168(9), 968–978. doi:10.1176/appi.ajp.2011.10091290
- Fox, C. J., Moon, S. Y., Iaria, G., & Barton, J. J. S. (2009). The correlates of subjective perception of identity and expression in the face network: An fMRI adaptation study. *NeuroImage*, 44(2), 569–580. doi:10.1016/j.neuroimage.2008.09.011
- Franklin, T. B., Saab, B. J., & Mansuy, I. M. (2012). Neural Mechanisms of Stress Resilience and Vulnerability. *Neuron*, 75(5), 747–761. doi:10.1016/j.neuron.2012.08.016
- Frith, C. (2009). Role of facial expressions in social interactions. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364(1535), 3453–3458. doi:10.1098/rstb.2009.0142
- Fusar-Poli, P., Placentino, A., Carletti, F., Allen, P., Landi, P., Abbamonte, M., ... Politi, P. L. (2009). Laterality effect on emotional faces processing: ALE meta-analysis of

- evidence. *Neuroscience Letters*, 452(3), 262–267. doi:10.1016/j.neulet.2009.01.065
- Ganel, T., Valyear, K. F., Goshen-Gottstein, Y., & Goodale, M. A. (2005). The involvement of the “fusiform face area” in processing facial expression. *Neuropsychologia*, 43(11), 1645–1654. doi:10.1016/j.neuropsychologia.2005.01.012
- Gee, D. G., Gabard-Durnam, L. J., Flannery, J., Goff, B., Humphreys, K. L., Telzer, E. H., ... Tottenham, N. (2013). Early developmental emergence of human amygdala-prefrontal connectivity after maternal deprivation. *Proceedings of the National Academy of Sciences of the United States of America*, 110(39), 15638–15643. doi:10.1073/pnas.1307893110
- Goetz, S. M. M., Tang, L., Thomason, M. E., Diamond, M. P., Hariri, A. R., & Carré, J. M. (2014). Testosterone rapidly increases neural reactivity to threat in healthy men: a novel two-step pharmacological challenge paradigm. *Biological Psychiatry*, 76(4), 324–331. doi:10.1016/j.biopsych.2014.01.016
- Gollier-Briant, F., Paillère-Martinot, M.-L., Lemaitre, H., Miranda, R., Vulser, H., Goodman, R., ... Artiges, E. (2016). Neural correlates of three types of negative life events during angry face processing in adolescents. *Social Cognitive and Affective Neuroscience*, 11(12), 1961–1969. doi:10.1093/scan/nsw100
- Hammen, C., Henry, R., & Daley, S. E. (2000). Depression and sensitization to stressors among young women as a function of childhood adversity. *Journal of Consulting and Clinical Psychology*, 68(5), 782–787. doi:10.1037/0022-006X.68.5.782
- Hariri, A. R., Bookheimer, S. Y., & Mazziotta, J. C. (2000). Modulating emotional responses. *NeuroReport*, 11(1), 43–48. doi:10.1097/00001756-200001170-00009
- Haxby, J. V., Hoffman, E. A., & Gobbini, M. I. (2000). The distributed human neural system for face perception. *Trends in Cognitive Sciences*, 4(6), 223–233. doi:10.1016/S1364-6613(00)01482-0

- Hazel, N. A., Hammen, C., Brennan, P. A., & Najman, J. (2008). Early childhood adversity and adolescent depression: the mediating role of continued stress. *Psychological Medicine*, 38(4), 581–589. doi:10.1017/S0033291708002857
- Jedd, K., Hunt, R. H., Cicchetti, D., Hunt, E., Cowell, R. A., Rogosch, F. A., ... Thomas, K. M. (2015). Long-term consequences of childhood maltreatment: Altered amygdala functional connectivity. *Development and Psychopathology*, 27, 1577–1589. doi:10.1017/S0954579415000954
- Jenness, J. L., Hankin, B. L., Young, J. F., & Smolen, A. (2016). Stressful life events moderate the relationship between genes and biased attention to emotional faces in youth. *Clinical Psychological Science*, 4(3), 386–400. doi:10.1177/2167702615601000
- Joormann, J., & Gotlib, I. H. (2007). Selective attention to emotional faces following recovery from depression. *Journal of Abnormal Psychology*, 116(1), 80–85. doi:10.1037/0021-843X.116.1.80
- Kensinger, E. A., & Schacter, D. L. (2006). Processing emotional pictures and words: Effects of valence and arousal. *Cognitive, Affective, & Behavioral Neuroscience*, 6(2), 110–126. doi:10.3758/CABN.6.2.110
- Kohn, N., Eickhoff, S. B., Scheller, M., Laird, A. R., Fox, P. T., & Habel, U. (2014). Neural network of cognitive emotion regulation - An ALE meta-analysis and MACM analysis. *NeuroImage*, 87, 345–355. doi:10.1016/j.neuroimage.2013.11.001
- Kragel, P. A., & LaBar, K. S. (2016). Somatosensory Representations Link the Perception of Emotional Expressions and Sensory Experience. *ENeuro*, 3(2), 0090. doi:10.1523/eneuro.0090-15.2016
- Lander, K., & Butcher, N. (2015). Independence of face identity and expression processing: exploring the role of motion. *Frontiers in Psychology*, 6, 255. doi:10.3389/fpsyg.2015.00255

- Larøi, F., Fonteneau, B., Mourad, H., & Raballo, A. (2010). Basic Emotion Recognition and Psychopathology in Schizophrenia. *The Journal of Nervous and Mental Disease*, 198(1), 79–81. doi:10.1097/NMD.0b013e3181c84cb0
- Levine, S. (2005). Developmental determinants of sensitivity and resistance to stress. *Psychoneuroendocrinology*, 30(10), 939–946. doi:10.1016/j.psyneuen.2005.03.013
- Liu, J., Harris, A., & Kanwisher, N. (2010). Perception of Face Parts and Face Configurations: An fMRI Study. *Journal of Cognitive Neuroscience*, 22(1), 203–211. doi:10.1162/jocn.2009.21203
- Maheu, F. S., Dozier, M., Guyer, A. E., Mandell, D., Peloso, E., Poeth, K., ... Ernst, M. (2010). A preliminary study of medial temporal lobe function in youths with a history of caregiver deprivation and emotional neglect. *Cognitive, Affective, & Behavioral Neuroscience*, 10(1), 34–49. doi:10.3758/CABN.10.1.34
- Mar, R. A. (2011). The Neural Bases of Social Cognition and Story Comprehension. *Annual Review of Psychology*, 62(1), 103–134. doi:10.1146/annurev-psych-120709-145406
- Masten, C. L., Guyer, A. E., Hodgdon, H. B., McClure, E. B., Charney, D. S., Ernst, M., ... Monk, C. S. (2008). Recognition of facial emotions among maltreated children with high rates of post-traumatic stress disorder. *Child Abuse & Neglect*, 32(1), 139–153. doi:10.1016/j.chiabu.2007.09.006
- McCrory, E. J., De Brito, S. A., Kelly, P. A., Bird, G., Sebastian, C. L., Mechelli, A., ... Viding, E. (2013). Amygdala activation in maltreated children during pre-attentive emotional processing. *British Journal of Psychiatry*, 202(04), 269–276. doi:10.1192/bjp.bp.112.116624
- McEwen, B. S., Bowles, N. P., Gray, J. D., Hill, M. N., Hunter, R. G., Karatsoreos, I. N., & Nasca, C. (2015). Mechanisms of stress in the brain. *Nature Neuroscience*, 18(10), 1353–1363. doi:10.1038/nn.4086

- McEwen, B. S., & Gianaros, P. J. (2011). Stress- and allostasis-induced brain plasticity. *Annual Review of Medicine*, 62, 431–445. doi:10.1146/annurev-med-052209-100430
- McLaughlin, K. A., Conron, K. J., Koenen, K. C., & Gilman, S. E. (2010). Childhood adversity, adult stressful life events, and risk of past-year psychiatric disorder: a test of the stress sensitization hypothesis in a population-based sample of adults. *Psychological Medicine*, 40(10), 1647–1658. doi:10.1017/S0033291709992121
- McLaughlin, K., McLaughlin, K. A., & Sheridan, M. A. (2016). Beyond Cumulative Risk: A Dimensional Approach to Childhood Adversity. *Current Directions in Psychological Science*, 25(4), 239–245. doi:10.1177/0963721416655883
- Nagy, K., Greenlee, M. W., & Kovács, G. (2012). The lateral occipital cortex in the face perception network: an effective connectivity study. *Frontiers in Psychology*, 3, 141. doi:10.3389/fpsyg.2012.00141
- Nederhof, E., Ormel, J., & Oldehinkel, A. J. (2014). Mismatch or Cumulative Stress: The Pathway to Depression Is Conditional on Attention Style. *Psychological Science*, 25(3), 684–692. doi:10.1177/0956797613513473
- Nederhof, E., & Schmidt, M. V. (2012). Mismatch or cumulative stress: Toward an integrated hypothesis of programming effects. *Physiology & Behavior*, 106(5), 691–700. doi:10.1016/j.physbeh.2011.12.008
- Nurius, P. S., Green, S., Logan-Greene, P., & Borja, S. (2015). Life course pathways of adverse childhood experiences toward adult psychological well-being: A stress process analysis. *Child Abuse & Neglect*, 45, 143–153. doi:10.1016/j.chiabu.2015.03.008
- Nusslock, R., & Miller, G. E. (2016). Early-Life Adversity and Physical and Emotional Health Across the Lifespan: A Neuroimmune Network Hypothesis. *Biological Psychiatry*, 80(1), 23–32. doi:10.1016/j.biopsych.2015.05.017
- Olszanowski, M., Pochwatko, G., Kuklinski, K., Scibor-Rylski, M., Lewinski, P., & Ohme, R.

- K. (2015). Warsaw set of emotional facial expression pictures: a validation study of facial display photographs. *Frontiers in Psychology*, 5, 1516.
doi:10.3389/fpsyg.2014.01516
- Oomen, C. A., Soeters, H., Audureau, N., Vermunt, L., van Hasselt, F. N., Manders, E. M. M., ... Krugers, H. (2010). Severe Early Life Stress Hampers Spatial Learning and Neurogenesis, but Improves Hippocampal Synaptic Plasticity and Emotional Learning under High-Stress Conditions in Adulthood. *Journal of Neuroscience*, 30(19), 6635–6645. doi:10.1523/jneurosci.0247-10.2010
- Palgi, Y., Shrira, A., Ben-Ezra, M., Shiovitz-Ezra, S., & Ayalon, L. (2012). Self- and other-oriented potential lifetime traumatic events as predictors of loneliness in the second half of life. *Aging & Mental Health*, 16(4), 423–430. doi:10.1080/13607863.2011.638903
- Paquola, C., Bennett, M. R., Hatton, S. N., Hermens, D. F., & Lagopoulos, J. (2017). Utility of the cumulative stress and mismatch hypotheses in understanding the neurobiological impacts of childhood abuse and recent stress in youth with emerging mental disorder. *Human Brain Mapping*, 38(5), 2709–2721. doi:10.1002/hbm.23554
- Pechtel, P., & Pizzagalli, D. A. (2011). Effects of early life stress on cognitive and affective function: an integrated review of human literature. *Psychopharmacology*, 214(1), 55–70. doi:10.1007/s00213-010-2009-2
- Phelps, E. A., & LeDoux, J. E. (2005). Contributions of the Amygdala to Emotion Processing: From Animal Models to Human Behavior. *Neuron*, 48(2), 175–187.
doi:10.1016/j.neuron.2005.09.025
- Phillips, M. L., Ladouceur, C. D., & Drevets, W. C. (2008). A neural model of voluntary and automatic emotion regulation: Implications for understanding the pathophysiology and neurodevelopment of bipolar disorder. *Molecular Psychiatry*, 13(9), 833–857.
doi:10.1038/mp.2008.65

- Pine, D. S., Mogg, K., Bradley, B. P., Montgomery, L., Christopher Monk, M. S., McClure, E., ... Kaufman, J. (2005). Attention Bias to Threat in Maltreated Children: Implications for Vulnerability to Stress-Related Psychopathology. *American Journal of Psychiatry*, *162*(2), 291–296. doi:10.1176/appi.ajp.162.2.291
- Pitcher, D., Duchaine, B., & Walsh, V. (2014). Combined TMS and fMRI Reveal Dissociable Cortical Pathways for Dynamic and Static Face Perception. *Current Biology*, *24*(17), 2066–2070. doi:10.1016/j.cub.2014.07.060
- Pitcher, D., Duchaine, B., Walsh, V., Yovel, G., & Kanwisher, N. (2011). The role of lateral occipital face and object areas in the face inversion effect. *Neuropsychologia*, *49*(12), 3448–3453. doi:10.1016/j.neuropsychologia.2011.08.020
- Pitcher, D., Walsh, V., & Duchaine, B. (2011). The role of the occipital face area in the cortical face perception network. *Experimental Brain Research*, *209*(4), 481–493. doi:10.1007/s00221-011-2579-1
- Pitcher, D., Walsh, V., Yovel, G., & Duchaine, B. (2007). TMS Evidence for the Involvement of the Right Occipital Face Area in Early Face Processing. *Current Biology*, *17*(18), 1568–1573. doi:10.1016/j.cub.2007.07.063
- Rahe, R. H. (1975). Epidemiological Studies of Life Change and Illness. *The International Journal of Psychiatry in Medicine*, *6*(1–2), 133–146. doi:10.2190/JGRJ-KUMG-GKKA-HBGE
- Reuter-Lorenz, P. A., & Cappell, K. A. (2008). Neurocognitive Aging and the Compensation Hypothesis. *Current Directions in Psychological Science*, *17*(3), 177–182. doi:10.1111/j.1467-8721.2008.00570.x
- Sandman, C. A., Davis, E. P., & Glynn, L. M. (2012). Prescient Human Fetuses Thrive. *Psychological Science*, *23*(1), 93–100. doi:10.1177/0956797611422073
- Santarelli, S., Lesuis, S. L., Wang, X.-D., Wagner, K. V., Hartmann, J., Labermaier, C., ...

- Schmidt, M. V. (2014). Evidence supporting the match/mismatch hypothesis of psychiatric disorders. *European Neuropsychopharmacology*, 24(6), 907–918. doi:10.1016/j.euroneuro.2014.02.002
- Shmotkin, D., & Litwin, H. (2009). Cumulative adversity and depressive symptoms among older adults in Israel: the differential roles of self-oriented versus other-oriented events of potential trauma. *Social Psychiatry and Psychiatric Epidemiology*, 44(11), 989–997. doi:10.1007/s00127-009-0020-x
- Silvers, J. A., Weber, J., Wager, T. D., & Ochsner, K. N. (2015). Bad and worse: Neural systems underlying reappraisal of high-and low-intensity negative emotions. *Social Cognitive and Affective Neuroscience*, 10(2), 172–179. doi:10.1093/scan/nsu043
- Sokolov, A. A., Miall, R. C., & Ivry, R. B. (2017). The Cerebellum: Adaptive Prediction for Movement and Cognition. *Trends in Cognitive Sciences*, 21(5), 313–332. doi:10.1016/j.tics.2017.02.005
- Sokołowski, A., & Dragan, W. Ł. (2017). New Empirical Evidence on the Validity and the Reliability of the Early Life Stress Questionnaire in a Polish Sample. *Frontiers in Psychology*, 8, 365. doi:10.3389/fpsyg.2017.00365
- Swain, R. A., Kerr, A. L., & Thompson, R. F. (2011). The Cerebellum: A Neural System for the Study of Reinforcement Learning. *Frontiers in Behavioral Neuroscience*, 5, 8. doi:10.3389/fnbeh.2011.00008
- Taylor, S. E., Eisenberger, N. I., Saxbe, D., Lehman, B. J., & Lieberman, M. D. (2006). Neural Responses to Emotional Stimuli Are Associated with Childhood Family Stress. *Biological Psychiatry*, 60(3), 296–301. doi:10.1016/j.biopsych.2005.09.027
- Tong, F., Nakayama, K., Moscovitch, M., Weinrib, O., & Kanwisher, N. (2000). Response properties of the human fusiform face area. *Cognitive Neuropsychology*, 17(1–3), 257–280. doi:10.1080/026432900380607

Tottenham, N., Hare, T. A., Millner, A., Gilhooly, T., Zevin, J. D., & Casey, B. J. (2011).

Elevated amygdala response to faces following early deprivation. *Developmental Science*, 14(2), 190–204. doi:10.1111/j.1467-7687.2010.00971.x

Uddin, L. Q., Kelly, A. M., Biswal, B. B., Castellanos, F. X., & Milham, M. P. (2009).

Functional connectivity of default mode network components: correlation, anticorrelation, and causality. *Human Brain Mapping*, 30(2), 625–637.

doi:10.1002/hbm.20531

van Harmelen, A.-L., van Tol, M.-J., Demenescu, L. R., van der Wee, N. J. A., Veltman, D.

J., Aleman, A., ... Elzinga, B. M. (2013). Enhanced amygdala reactivity to emotional faces in adults reporting childhood emotional maltreatment. *Social Cognitive and Affective Neuroscience*, 8(4), 362–369. doi:10.1093/scan/nss007

van Marle, H. J. F., Hermans, E. J., Qin, S., & Fernández, G. (2009). From Specificity to

Sensitivity: How Acute Stress Affects Amygdala Processing of Biologically Salient Stimuli. *Biological Psychiatry*, 66(7), 649–655. doi:10.1016/j.biopsych.2009.05.014

Vuilleumier, P., Armony, J. L., Driver, J., & Dolan, R. J. (2001). Effects of Attention and

Emotion on Face Processing in the Human Brain: An Event-Related fMRI Study.

Neuron, 30(3), 829–841. doi:10.1016/S0896-6273(01)00328-2

Winston, J. ., O'Doherty, J., & Dolan, R. . (2003). Common and distinct neural responses

during direct and incidental processing of multiple facial emotions. *NeuroImage*, 20(1), 84–97. doi:10.1016/S1053-8119(03)00303-3

Xu, X., & Biederman, I. (2010). Loci of the release from fMRI adaptation for changes in

facial expression, identity, and viewpoint. *Journal of Vision*, 10(14), 36–36.

doi:10.1167/10.14.36

Zalosnik, M. I., Pollano, A., Trujillo, V., Suárez, M. M., & Durando, P. E. (2014). Effect of

maternal separation and chronic stress on hippocampal-dependent memory in young

adult rats: evidence for the match-mismatch hypothesis. *Stress*, 17(5), 445–450.

doi:10.3109/10253890.2014.936005

Zhen, Z., Fang, H., & Liu, J. (2013). The Hierarchical Brain Network for Face Recognition.

PLoS ONE, 8(3), e59886. doi:10.1371/journal.pone.0059886

Supplementary Material

ALE Meta-analysis.

Table S 1.

Studies concerning face perception and emotional expression processing included in the ALE meta-analysis.

	Coordinates (MNI)		
	x	y	z
Ambrus, Windel, Burton, & Kovács (2017)			
OFA R	42.64	-78.05	-8.47
OFA R	42.10	-77.60	-8.60
Axelrod & Yovel (2013)			
FFA L	-41	-59	-20
FFA R	40	-56	-20
pSTS L	-53	-57	8
pSTS R	52	-51	8
Axelrod & Yovel (2015)			
FFA L	-41	-53	-18
FFA R	39	-52	-16
pSTS L	-51	-54	11
pSTS R	52	-42	10
Beer et al. (2016)			
FFA R	37.69	-47.18	-21.85
Bilalić, Grottenhaler, Nägele, & Lindig (2016)			
FFA L	-45	-54	-21
FFA R	45	-54	-15
pSTS R	48	-36	0
Bona, Cattaneo, & Silvanto (2016)			
OFA R	39	-81	-10
Candidi, Stienen, Aglioti, & de Gelder (2015)			
pSTS R	56.37	-48.76	8.63
Carlin & Kriegeskorte (2017)			
FFA L	-39	-55	-20
FFA R	41.5	-50.5	-20.7
OFA L	-41.4	-82	-14.3
OFA R	43.5	-75.5	-12.6
Contreras, Banaji, & Mitchell (2013)			
FFA L	-37.1	-47.6	-17.3
FFA R	38.8	-44.3	-18.5
OFA L	-33.1	-77	-6.55
OFA R	33.3	-76.7	-8.9
pSTS L	-49.8	-52.8	21.3

pSTS R	49.8	-43.4	13.9
Davies-Thompson et al. (2018)			
FFA L	-42	-55	-26
FFA R	42	-58	-17
OFA L	-38	-78	-8
OFA R	39	-81	-11
pSTS L	-49	-55	15
pSTS R	51	-51	12
Engell, Kim, & McCarthy (2018)			
FFA R	44	-48	-22
OFA R	48	-76	-6
Goffaux, Schiltz, Mur, & Goebel (2013)			
FFA L	-40.08	-48.42	-19.28
FFA R	40.92	-45.04	-22.12
OFA L	-39.92	-75.65	-12.11
OFA R	44.36	-73.13	-12.67
Goffaux, Duecker, Hausfeld, Schiltz, & Goebel (2016)			
FFA L	-42.2	-51.41	-16.71
FFA R	41.02	-48.68	-15.04
OFA L	-39.74	-76.54	1.42
OFA R	40.16	-76.56	-3.3
Jiang, Badler, Righi, & Rossion (2015)			
FFA L	-41.12	-52.47	-16.62
FFA R	42.08	-54.3	-17.86
OFA L	-33.4	-85.2	-11.27
OFA R	34.72	-87.84	-8.81
pSTS R	54.24	-44.53	5.62
McGugin, Van Gulick, & Gauthier (2016)			
FFA L	-41.19	-63.93	-24.45
FFA L	-42.35	-43.73	-26.43
FFA R	44.18	-63.53	-24.83
FFA R	44.1	-41.09	-25.92
OFA L	-35.7	-86.25	-22.34
OFA R	32.39	-90.16	-21.99
Nguyen & Cunningham (2014)			
FFA L	-41	-51	-18
FFA R	41	-52	-16
OFA L	-40	-74	-13
OFA R	41	-73	-12
pSTS R	55	-55	11
Nichols, Betts, & Wilson (2016)			
FFA L	-37.89	-53.62	-17.68
FFA R	42.09	-53.13	-16.85

OFA L	-38.76	-78.32	-6.26
OFA R	45.5	-74.83	-8.04
Pajani, Kouider, Roux, & de Gardelle (2017)			
FFA L	-42	-51	-20
FFA R	43	-48	-20
OFA L	-42	-76	-11
OFA R	45	-73	-10
Pitcher (2014)			
OFA R	42	-79	-10
pSTS R	51	-70	2
Sauder, Hajcak, Angstadt, & Phan (2013)			
FFA L	-33	-60	-15
FFA L	-34	-62	-16
FFA R	33	-59	-15
FFA R	34	-60	-15
Slotnick & White (2013)			
FFA L	-38.98	-53.73	-18.78
FFA R	42.02	-47.06	-20.82
OFA L	-41.83	-77.09	7.12
OFA R	48.91	-73.58	5.22
pSTS L	-51.54	-57.35	12.05
pSTS R	52.17	-56.99	10.25
Sunday, McGugin, Tamber-Rosenau, & Gauthier (2018)			
FFA L	-41.62	-64.6	-19.2
FFA L	-42.22	-49.78	-22.3
FFA R	41.02	-64.8	-18.37
FFA R	40.72	-47.29	-23.89
OFA L	-39.41	-82.09	-15.87
OFA R	33.68	-82.85	-17.13
Bi, Chen, Zhou, He, & Fang (2014)			
FFA L	-43.26	-49.08	-14.68
FFA R	42.07	-48.88	-17.27
OFA L	-38.81	-75.44	-9.91
OFA R	40.06	-75.16	-11.28
pSTS L	-51.51	-55.98	15.28
pSTS R	52.17	-50.4	11.84
Weibert & Andrews (2015)			
FFA L	-42	-48	-24
FFA R	40	-52	-26
OFA L	-40	-82	-18
OFA R	48	-76	-8
pSTS L	-56	-60	6
pSTS R	46	-66	8

Yang et al. (2016)			
pSTS L	-57	-62	9
pSTS R	55	-59	7
Young et al. (2017)			
FFA L	-40	-51.6	-17.3
FFA R	40.9	-42.9	-18.4
Zachariou, Safiullah, & Ungerleider (2018)			
FFA L	-38.97	-48.21	-17.08
FFA R	44.21	-51.21	-19.32
OFA L	-44.09	-76.76	-0.72
OFA R	47.72	-76.54	-3.43
Zebrowitz, Ward, Boshyan, Gutchess, & Hadjikhani (2016)			
FFA R	42	-46	-26
Zhang et al. (2016)			
FFA R	44.14	-47.37	-24.18
OFA R	42.23	-78.35	-11
pSTS R	48.96	-45.84	14.8
Zhou et al. (2018)			
FFA L	-40	-53	-19
FFA R	42	-51	-18
OFA L	-40	-79	-11
OFA R	40	-77	-11

FFA–fusiform face area; L–left; OFA–occipital face area; pSTS–posterior superior temporal sulcus; R–right.

Behavioral Results.

Table S2.

Accuracy and reaction times on the face-matching task.

	ES-/RS- group <i>M (SD)</i>	ES-/RS+ group <i>M (SD)</i>	ES+/RS- group <i>M (SD)</i>	ES+/RS+ group <i>M (SD)</i>
Accuracy (fear)	95.45 (9.18)	96.67 (8.72)	96.59 (11.11)	94.05 (10.26)
Accuracy (anger)	94.32 (9.75)	96.67 (4.99)	95.45 (11.13)	93.65 (10.17)
Accuracy (disgust)	98.48 (3.29)	97.08 (6.21)	96.97 (7.52)	97.22 (8.87)
Accuracy (neutral)	96.78 (5.88)	97.5 (5.26)	97.44 (9.32)	95.44 (8.48)
RT (fear)	1.70 (0.36)	1.63 (0.34)	1.55 (0.26)	1.54 (0.51)
RT (anger)	1.78 (0.36)	1.71 (0.33)	1.71 (0.33)	1.66 (0.41)
RT (disgust)	1.62 (0.31)	1.59 (0.27)	1.59 (0.27)	1.55 (0.44)
RT (neutral)	1.20 (0.22)	1.15 (0.15)	1.24 (0.23)	1.20 (0.37)

ES—early stress; RS—recent stress; RT—reaction time. Accuracy given in percent (%), reaction times in seconds (s).

Figure S1. Accuracy rate on the face-matching task for each group. Errors bars represent standard errors. ES—early stress; RS—recent stress.

Figure S2. Reaction times on the face-matching task for each group. Errors bars represent standard errors. ES—early stress; RS—recent stress.

Whole-brain Analysis.

Table S 3.

Whole-brain analysis for the face-matching task across all participants (negative emotional expressions > neutral faces).

Brain region		x	y	z	T	k
Emotional > Neutral						
Fusiform gyrus	L	-40	-50	-16	12.17	6520
Inferior occipital gyrus	L	-30	-88	-6	11.37	lm
Inferior occipital gyrus	L	-40	-78	-8	11.22	lm
Inferior occipital gyrus	R	34	-86	-6	11.24	7345
Occipital fusiform gyrus	R	38	-64	-12	10.88	lm
Inferior occipital gyrus	R	48	-74	-4	10.33	lm
Inferior frontal gyrus	R	44	12	26	9.94	4604
Precentral gyrus	R	58	14	40	8.41	lm
Precentral gyrus	R	50	4	52	8.29	lm
Precentral/inferior frontal gyrus	L	-38	4	28	8.68	4174
Middle frontal gyrus	L	-48	14	32	8.13	lm
Middle frontal gyrus	L	-54	28	28	7.80	lm
Paracingulate gyrus/SMA	L	-6	12	50	6.89	594
Neutral > Emotional						
Posterior cingulate gyrus	R	2	-30	42	7.82	12076
Paracingulate gyrus	L	-2	54	2	7.34	lm
Paracingulate gyrus/ACC	R	-10	48	6	6.83	lm
Angular gyrus	R	60	-54	36	6.35	669
Angular gyrus	R	60	-52	44	6.01	lm
Middle occipital gyrus	R	48	-72	30	5.15	lm
sLOC	L	-42	-80	34	6.17	709
Angular gyrus	L	-52	-58	36	4.28	lm
Planum polare	R	58	-2	2	5.83	1210
Middle temporal gyrus	R	66	-16	-14	5.09	lm
Superior temporal gyrus	R	64	-14	4	4.76	lm
Planum temporale	L	-50	-34	12	4.59	805
Superior temporal gyrus	L	-62	-20	4	4.51	lm
Heschl's gyrus	L	-54	-8	0	4.17	lm

Coordinates in MNI space; L–left hemisphere; lm–local maximum; R–right hemisphere.

ACC–anterior cingulate cortex; sLOC–superior lateral occipital cortex; SMA–supplementary motor area. $p < .001$ (unc.); FWE < .05.

Figure S3. Whole-brain analysis across all participants (negative emotional expressions > neutral faces). Warm colors indicate stronger activation for emotional expressions; cool colors indicate deactivation. Abbreviations: ACC—anterior cingulate cortex; FuG—fusiform gyrus; IFG—inferior frontal gyrus; IOG—inferior occipital gyrus; MFG—middle frontal gyrus; MOG—middle occipital gyrus; MTG—middle temporal gyrus; PCC—posterior cingulate cortex; PrG—precentral gyrus; SFG—superior frontal gyrus; SMA—supplementary motor area; STG—superior temporal gyrus.

Table S 4.

Main effects of early life and recent stress on functional connectivity during the face-matching task.

Seed	Contrast and brain region		k	P (FDR)	β	x	y	z
Left FFA	Main effect of ES (ES– > ES+)							
	PrG	R	590	.000	.25	38	-10	58
	SPL	R	456	.000	.24	18	-46	54
Right FFA	Main effect of ES (ES– > ES+)							
	sLOC	R	168	.003	.26	24	-70	32
	PAC/SFG	L	149	.003	.25	-4	12	52
	Main effect of RS (RS+ > RS–)							
	Cerebellum	R	131	.004	.25	14	-52	-18
Right OFA	Main effect of ES (ES– > ES+)							
	Heschl's gyrus	L	442	.000	.25	-42	-36	6
Left pSTS	Main effect of ES (ES– > ES+)							
	Heschl's gyrus	L	355	.000	.25	-42	-26	10
Right pSTS	Main effect of RS (RS+ > RS–)							
	Caudate	R	186	.000	.22	14	4	16
	Putamen	R	120	.003	.23	22	20	-6
	Insula	R	90	.008	.23	36	-8	-8

Regions are defined by MNI coordinates. ES–early stress; FFA–fusiform face area; L–left hemisphere; OFA–occipital face area; PAC–paracingulate gyrus; pSTS–posterior superior temporal sulcus; PrG–precentral gyrus; R–right hemisphere; RS–recent stress; SFG–superior frontal gyrus; sLOC–superior lateral occipital cortex; SPL–superior parietal lobule.

Amygdala seeds.

No functional connectivity was observed in the amygdala seeds.

Left FFA seed.

A main effect of early life stress was observed for functional connectivity between the left FFA and right precentral gyrus (PrG) as well as the superior parietal lobule (SPL). The ES+ group exhibited negative connectivity with the PrG gyrus ($\beta = -.14$), while the ES– group exhibited positive connectivity ($\beta = .11$). The ES+ group exhibited negative connectivity with SPL ($\beta = -.17$), while the ES– group showed positive connectivity ($\beta = .08$).

Right FFA seed.

A main effect of early life stress was observed for the left FFA and right superior lateral occipital cortex (sLOC) as well as left paracingulate cortex (PAC) coupling. Negative connectivity with the right sLOC was observed in the ES+ group ($\beta = -.23$), while there was slight positive connectivity in the ES– group ($\beta = .03$). The ES+ group exhibited negative

connectivity with the left PAR ($\beta = -.07$), while the ES– group showed positive connectivity ($\beta = .19$). There was a main effect of recent stress on left FFA and right cerebellum coupling. The RS+ group had positive connectivity ($\beta = .09$), while the RS– group had negative connectivity ($\beta = -.16$).

Right OFA seed.

A main effect of early life stress was observed for right OFA and left Heschl's gyrus connectivity. The ES+ group exhibited negative connectivity ($\beta = -.15$), while the ES– group showed positive connectivity ($\beta = .10$) between these regions.

Left pSTS seed.

A main effect of early life stress was observed for left pSTS and left Heschl's gyrus connectivity. The ES+ group exhibited negative connectivity ($\beta = -.11$), while the ES– group showed positive connectivity ($\beta = .14$) between these regions.

Right pSTS seed.

A main effect of recent stress was observed for functional connectivity between the right pSTS and right caudate, putamen, and insula. The RS+ group exhibited positive connectivity with the right caudate ($\beta = .18$), while the RS– group displayed negative connectivity ($\beta = -.05$). The RS+ group exhibited positive connectivity with the right putamen ($\beta = .16$), while the RS– group showed negative connectivity ($\beta = -.08$). The RS+ group exhibited positive connectivity with the right insula ($\beta = .12$), while the RS– group had negative connectivity ($\beta = -.11$).

References

- Ambrus, G. G., Windel, F., Burton, A. M., & Kovács, G. (2017). Causal evidence of the involvement of the right occipital face area in face-identity acquisition. *NeuroImage*, 148, 212–218. doi:10.1016/j.neuroimage.2017.01.043
- Axelrod, V., & Yovel, G. (2013). The challenge of localizing the anterior temporal face area: A possible solution. *NeuroImage*, 81, 371–380. doi:10.1016/j.neuroimage.2013.05.015
- Axelrod, V., & Yovel, G. (2015). Successful Decoding of Famous Faces in the Fusiform Face Area. *PLOS ONE*, 10(2), e0117126. doi:10.1371/journal.pone.0117126
- Beer, J. C., Smith, A. R., Jarcho, J. M., Chen, G., Reynolds, R. C., Pine, D. S., & Nelson, E. E. (2016). Anxiously elaborating the social percept: Anxiety and age differences in functional connectivity of the fusiform face area in a peer evaluation paradigm. *Australian Journal of Psychology*, 68(3), 154–165. doi:10.1111/ajpy.12130
- Bi, T., Chen, J., Zhou, T., He, Y., & Fang, F. (2014). Function and Structure of Human Left Fusiform Cortex Are Closely Associated with Perceptual Learning of Faces. *Current Biology*, 24(2), 222–227. doi:10.1016/j.cub.2013.12.028
- Bilalić, M., Grottenhaler, T., Nägele, T., & Lindig, T. (2016). The Faces in Radiological

- Images: Fusiform Face Area Supports Radiological Expertise. *Cerebral Cortex*, 26(3), 1004–1014. doi:10.1093/cercor/bhu272
- Bona, S., Cattaneo, Z., & Silvanto, J. (2016). Investigating the Causal Role of rOFA in Holistic Detection of Mooney Faces and Objects: An fMRI-guided TMS Study. *Brain Stimulation*, 9(4), 594–600. doi:10.1016/j.brs.2016.04.003
- Candidi, M., Stienen, B. M. C., Aglioti, S. M., & de Gelder, B. (2015). Virtual lesion of right posterior superior temporal sulcus modulates conscious visual perception of fearful expressions in faces and bodies. *Cortex*, 65, 184–194. doi:10.1016/j.cortex.2015.01.012
- Carlin, J. D., & Kriegeskorte, N. (2017). Adjudicating between face-coding models with individual-face fMRI responses. *PLOS Computational Biology*, 13(7), e1005604. doi:10.1371/journal.pcbi.1005604
- Contreras, J. M., Banaji, M. R., & Mitchell, J. P. (2013). Multivoxel Patterns in Fusiform Face Area Differentiate Faces by Sex and Race. *PLoS ONE*, 8(7), e69684. doi:10.1371/journal.pone.0069684
- Davies-Thompson, J., Elli, G. V, Rezk, M., Benetti, S., van Ackeren, M., & Collignon, O. (2018). Hierarchical Brain Network for Face and Voice Integration of Emotion Expression. *Cerebral Cortex*, bhy240, 1–16. doi:10.1093/cercor/bhy240
- Engell, A. D., Kim, N. Y., & McCarthy, G. (2018). Sensitivity to Faces with Typical and Atypical Part Configurations within Regions of the Face-processing Network: An fMRI Study. *Journal of Cognitive Neuroscience*, 30(7), 963–972. doi:10.1162/jocn_a_01255
- Goffaux, V., Duecker, F., Hausfeld, L., Schiltz, C., & Goebel, R. (2016). Horizontal tuning for faces originates in high-level Fusiform Face Area. *Neuropsychologia*, 81, 1–11. doi:10.1016/j.neuropsychologia.2015.12.004
- Goffaux, V., Schiltz, C., Mur, M., & Goebel, R. (2013). Local Discriminability Determines the Strength of Holistic Processing for Faces in the Fusiform Face Area. *Frontiers in Psychology*, 3(604), 1–14. doi:10.3389/fpsyg.2012.00604
- Jiang, F., Badler, J. B., Righi, G., & Rossion, B. (2015). Category search speeds up face-selective fMRI responses in a non-hierarchical cortical face network. *Cortex*, 66, 69–80. doi:10.1016/j.cortex.2015.01.025
- McGugin, R. W., Van Gulick, A. E., & Gauthier, I. (2016). Cortical Thickness in Fusiform Face Area Predicts Face and Object Recognition Performance. *Journal of Cognitive Neuroscience*, 28(2), 282–294. doi:10.1162/jocn_a_00891
- Nguyen, V. T., & Cunnington, R. (2014). The superior temporal sulcus and the N170 during face processing: Single trial analysis of concurrent EEG–fMRI. *NeuroImage*, 86, 492–502. doi:10.1016/j.neuroimage.2013.10.047
- Nichols, D. F., Betts, L. R., & Wilson, H. R. (2016). Position selectivity in face-sensitive visual cortex to facial and nonfacial stimuli: an fMRI study. *Brain and Behavior*, 6(11), e00542. doi:10.1002/brb3.542
- Pajani, A., Kouider, S., Roux, P., & de Gardelle, V. (2017). Unsuppressible Repetition Suppression and exemplar-specific Expectation Suppression in the Fusiform Face Area. *Scientific Reports*, 7, 160. doi:10.1038/s41598-017-00243-3
- Pitcher, D. (2014). Facial Expression Recognition Takes Longer in the Posterior Superior Temporal Sulcus than in the Occipital Face Area. *Journal of Neuroscience*, 34(27), 9173–9177. doi:10.1523/jneurosci.5038-13.2014

- Sauder, C. L., Hajcak, G., Angstadt, M., & Phan, K. L. (2013). Test-retest reliability of amygdala response to emotional faces. *Psychophysiology*, 50(11), 1147–1156. doi:10.1111/psyp.12129
- Slotnick, S. D., & White, R. C. (2013). The fusiform face area responds equivalently to faces and abstract shapes in the left and central visual fields. *NeuroImage*, 83, 408–417. doi:10.1016/j.neuroimage.2013.06.032
- Sunday, M. A., McGugin, R. W., Tamber-Rosenau, B. J., & Gauthier, I. (2018). Visual imagery of faces and cars in face-selective visual areas. *PLOS ONE*, 13(9), e0205041. doi:10.1371/journal.pone.0205041
- Weibert, K., & Andrews, T. J. (2015). Activity in the right fusiform face area predicts the behavioural advantage for the perception of familiar faces. *Neuropsychologia*, 75, 588–596. doi:10.1016/j.neuropsychologia.2015.07.015
- Yang, Z., Zhen, Z., Huang, L., Kong, X., Wang, X., Song, Y., & Liu, J. (2016). Neural Univariate Activity and Multivariate Pattern in the Posterior Superior Temporal Sulcus Differentially Encode Facial Expression and Identity. *Scientific Reports*, 6, 23427. doi:10.1038/srep23427
- Young, L. R., Yu, W., Holloway, M., Rodgers, B. N., Chapman, S. B., & Krawczyk, D. C. (2017). Amygdala activation as a marker for selective attention toward neutral faces in a chronic traumatic brain injury population. *Neuropsychologia*, 104, 214–222. doi:10.1016/j.neuropsychologia.2017.08.026
- Zachariou, V., Safiullah, Z. N., & Ungerleider, L. G. (2018). The Fusiform and Occipital Face Areas Can Process a Nonface Category Equivalently to Faces. *Journal of Cognitive Neuroscience*, 30(10), 1499–1516. doi:10.1162/jocn_a_01288
- Zebrowitz, L., Ward, N., Boshyan, J., Gutchess, A., & Hadjikhani, N. (2016). Dedifferentiated face processing in older adults is linked to lower resting state metabolic activity in fusiform face area. *Brain Research*, 1644, 22–31. doi:10.1016/j.brainres.2016.05.007
- Zhang, H., Japee, S., Nolan, R., Chu, C., Liu, N., & Ungerleider, L. G. (2016). Face-selective regions differ in their ability to classify facial expressions. *NeuroImage*, 130, 77–90. doi:10.1016/j.neuroimage.2016.01.045
- Zhou, G., Liu, J., Xiao, N. G., Wu, S. J., Li, H., & Lee, K. (2018). The Fusiform Face Area Plays a Greater Role in Holistic Processing for Own-Race Faces Than Other-Race Faces. *Frontiers in Human Neuroscience*, 12, 220. doi:10.3389/fnhum.2018.00220