Supplemental Material

for

Weakened vmPFC-amygdala functional connectivity is longitudinally related to psychopathic traits during early adulthood in low-income males

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Supplemental Methods

fMRI data acquisition

Each participant was scanned with a research-dedicated Siemens 3-T Tim Trio. Blood oxygenation level–dependent (BOLD) functional images were acquired with a gradient-echo echoplanar imaging (EPI) sequence (RT/ET=2000/29 milliseconds, FOV=200x200), which covered 34 interleaved axial slices (3-mm slice thickness) aligned with the AC-PC plane and encompassing the entire cerebrum and most of the cerebellum to maximum coverage of limbic structures. All scanning parameters were selected to optimize the quality of the BOLD signal while maintaining a sufficient number of slices to acquire whole-brain data. Before collecting fMRI data for each participant, a reference echoplanar imaging scan was acquired and visually inspected for artifacts (e.g., ghosting) and good signal across the entire volume of acquisition. Additionally, an autoshimming procedure was conducted before the acquisition of BOLD data in each participant to minimize field inhomogeneities.

fMRI data pre-processing

Functional data were analyzed in SPM8 (Statistical Parametric Mapping, Wellcome Trust Centre, United Kingdom). Images for each participant were segmented, realigned to the mean volume in the time series, unwarped to correct for head motion, co-registered to high resolution structural scans (MPRAGE), spatially normalized into a standard stereotactic space (MNI) using a 12-parameter affine model, and smoothed to minimize noise and residual difference in gyral anatomy with a Gaussian filter set at 6 mm FWHM. Voxelwise signal intensities were ratio-normalized to the whole-brain global mean. After preprocessing, the Artifact detection Tools (ART) software package

(http://www.nitrc.org/projects/artifact_detect/) was used to detect global mean intensity and translation or rotational motion outliers (>4.5 SD from the mean global brain activation, >2mm movement or 2^{o} translation in any direction) within each participant's data and to create regressors to account for the possible confounding effects of volumes as outliers. Additionally, because of the relatively extensive signal loss typically observed in the amygdala, single-subject BOLD fMRI data were only included in subsequent analyses with a minimum of 90% signal coverage in the amygdala bilaterally, defined using the Automated Anatomical Labeling (AAL) atlas in the WFU PickAtlas Tool, version 1.04 (Maldjian, Laurienti, Kraft, & Burdette, 2003).

Behavioral covariates.

In addition to controlling for race and income, we ran a further longitudinal model to account for continuity in traits related to psychopathy over time. Unfortunately, psychopathy was not directly measured until age 22. However, we were able to account for: (1) Earlier antisocial behavior (age 20) assessed using the 53-item Self-Report of Delinquency (α=.90; Elliott, Huizinga, & Ageton, 1985), and (2) Earlier callous-unemotional traits (age 20) assessed using a measure that combined the CU traits items from the Antisocial Process Screening Device (Frick & Hare, 2001) and 10 inversely-coded prosocial items from the Child and Adolescent Disposition Scale that assessed concern for others, helping, and sharing (Lahey et al., 2008). In a prior study using this sample, we showed that items from these two scales formed a single construct (α=.83; p. 1030, Waller, Shaw, Forbes, & Hyde, 2015). By modeling antisocial behavior and callous-unemotional traits at age 20, we could be more confident that links between amygdala-vmPFC functional connectivity at age 20 and psychopathic traits at age 22

were over and above expected continuity in these traits over time and reflected brain effects on behavior, rather than the reverse.

Supplemental Table 1. Sources of data loss for imaging paradigm

	Numbers
Original sample, *N* = 310	
Sample with imaging data at age 20	
- Concussion/head injury	25
- Bullets/metal fragments	15
- Braces	2
- Phone interviews (out of the area)	5
- Refused MRI portion of the visit	7
- Living at home/treatment facility (too ill to participate – schizophrenia, autism, car accident)	4
- Claustrophobic	8
- Left before scanning portion/wanted to stop scan	4
- Did not physically fit in the bore	1
- Reported being currently on drugs	1
Total lost	124
Participants with usable imaging data	**186**
Sample with usable imaging data at age 20	
- Incidental findings on sMRI	2
- Poor amygdala coverage (< 90%)	7
- Poor performance on task (< 75%)	1
- Slept during scan	1
- Excessive movement/outliers	1
- Psychosis	4
- Appeared to be on drugs and not responding to task	3
Total lost	19
Participants with available data for subsequent analyses	**167**

Supplemental Table 2. Activation in the left and right amygdala is negatively correlated with activation in the vmPFC while participants look at fearful, angry, or neutral faces versus shapes

		vmPFC target region
Contrast	*Amygdala Seed Region*	**(x,y,z), *t* extent threshold, *k* cluster size**
Fear < Shapes	left	(2,48,-2), *t* = 4.22**, *k* = 29**
	right	(8,40,-6), *t* = 4.33**, *k* = 31**
Angry < Shapes	left	(0,42,-4), *t* = 4.84***, *k* = 152***
	right	(2,44,4), *t* = 3.61**, *k* = 25*
Neutral < Shapes	left	(4,48,-4) , *t* = 3.93*, *k* = 11*
	right	(8,48,-2) , *t* = 4.33**, *k* = 38**

Note. * $p < .05$, ** $p < .01$, *** $p < .001$. Family-wise error corrected within the vmPFC mask (Acikalin, Gorgolewski, & Poldrack, 2017)

Supplemental Table 3. Descriptive statistics and bivariate correlations of main study variables

			Total SRP (age 22)	Factor 1	Factor 2	Int (age 22)	Aff (age 22)	Imp-life (age 22)	Anti-social (age 22)	Inc $ (age 20)	Anti-social (age 20)	CU traits (age 20)	Fear faces (age 20)	Angry faces (age 20)
	N	***M (SD)***												
Outcomes at age 22														
Total SRP psychopathy	151	56.01 (14.39)												
Factor 1 psychopathy	151	29.17 (8.81)	.95***											
Factor 2 psychopathy	151	27.21 (7.27)	.92***	.75***	.70***									
Interpersonal facet	151	13.19 (4.92)	.88***	.92***	.67***									
Affective facet	151	15.99 (4.61)	.86***	.92***	.90***	.70***								
Impulsive-lifestyle facet	151	16.30 (4.52)	.82***	.66***	.86***	.59***	.63***							
Antisocial facet	151	10.91 (3.73)	.80***	.66***	.86***	.65***	.56***	.55***						
Covariates at age 20														
Monthly income ($)	154	1386.26 (1898.00)	-.08	-.11	-.04	-.14	-.06	.05	-.14†					
Antisocial behavior	167	4.53 (4.90)	.41***	.34***	.43***	.33***	.30**	.43***	.32**	.08				
CU traits	167	-.04 (.96)	.42***	.40***	.38***	.36***	.39***	.31***	.36***	-.04	.20*			
vmPFC-amygdala negative functional connectivity estimates at age 20														
Fearful faces < Shapes	167	-.42 (1.10)	-.17*	-.12	-.20*	-.10	-.12	-.20*	-.16†	-.02	.01	-.05		
Angry faces < Shapes	167	-.23 (.64)	-.10	-.06	-.13	-.03	-.09	-.11	-.12	-.01	-.04	-.13†	.28***	
Neutral faces < Shapes	167	-.22 (.65)	.01	-.04	.03	-.05	-.02	-.03	.08	-.08	.03	-.10	.08	.14†

Note. ***$p < .001$, ** $p < .01$, * $p < .05$, † $p < .10$

Supplemental Table 4. At age 20, amygdala-vmPFC functional connectivity to fearful faces, but not neutral faces, is prospectively related to psychopathic traits at age 22.

	Outcome - **Psychopathic traits (age 22; total SRP score)**	
Model 1: Only race and income as covariates	B (SE)	β
Race	2.28 (2.39)	.08
Monthly income ($, age 20)	-1.03 (.83)	-.07
Fearful faces < Shapes	-2.13 (1.09)	-.16*
Angry faces < Shapes	1.36 (1.76)	-.06
Neutral faces < Shapes	-.10 (2.21)	-.004
Model 2: Race and income, and earlier antisocial behavior and CU traits as covariates		.06
Race	1.68 (1.94)	.06
Monthly income ($, age 20)	-.73 (.41)	-.09
Antisocial behavior (age 20)	1.07 (.21)	.35***
CU traits (age 20)	5.23 (1.29)	.34***
Fearful faces < Shapes	-2.07 (.97)	-.15*
Angry faces < Shapes	.42 (1.52)	.02
Neutral faces < Shapes	.70 (1.76)	.03

Note. ***$p < .001$, ** $p < .01$, * $p < .05$. We examined a multivariate SEM where we regressed total SRP psychopathy scores at age 22 onto predictors at age 20, while accounting for the covariance of predictors. Model 1 includes only race and income as covariates (model fit statistics: χ^2=4.22, df=4, CFI=.91, TLI=.89, RMSEA=.02, SRMR=.03). Model 2 includes race, income, and earlier antisocial behavior and CU traits at age 20 (model fit statistics: χ^2=6.06, df=6, CFI=.99, TLI=.99, RMSEA=.03, SRMR=.03). Over and above the continuity of antisocial behavior and CU traits with later psychopathy, weakened amygdala-vmPFC functional connectivity during the processing of fearful faces < shapes at age 20 (but not neutral faces < shapes or angry faces < shapes) was related to higher psychopathic traits at age 22.

Supplemental Table 5. Factor 2 psychopathy scores (i.e., irresponsible-lifestyle and antisocial behaviors) are related to weakened negative amygdala-vmPFC functional connectivity during the processing of fearful faces versus shapes

	Correlated outcomes (two factor scores of psychopathy at age 22)					
	Factor 1 (interpersonal/affective traits)			**Factor 2 (lifestyle-antisocial behaviors)**		
Model 1: Only race and income as covariates	B (SE)	95% bootstrapped confidence intervals	β	B (SE)	95% bootstrapped confidence intervals	β
Race	2.64 (1.39)	-.01, .31	.15†	-.36 (1.16)	-.19, .14	-.03
Monthly income ($)	-.40 (.29)	-.22, .05	-.09	-.15 (.21)	-.15, .07	-.04
Fearful faces < Shapes	-.93 (.63)	-.27, .04	-.12	-1.20 (.52)	.33, -.03	-.18*
Angry faces < Shapes	-.35 (1.05)	-.18, .13	-.03	-1.01 (.82)	-.23, .06	-.09
Neutral faces < Shapes	-.59 (1.23)	-.24, .15	-.04	.49 (1.01)	-.14, .23	.04
	Factor 1 (interpersonal/affective traits)			**Factor 2 (lifestyle-antisocial behaviors)**		
Model 2: Race and income, and earlier antisocial behavior and CU traits as covariates	B (SE)	95% bootstrapped confidence intervals	β	B (SE)	95% bootstrapped confidence intervals	β
Race	2.26 (1.69)	-.006, .27	.13†	-.58 (.96)	-.18, .10	-.04
Monthly income ($)	-.48 (.30)	-.24, .03	-.10	-.25 (.17)	-.16, .02	-.07
Antisocial behavior (age 20)	.52 (.14)	.15, .44	.29***	.55 (.10)	.24, .50	.37***
CU traits (age 20)	2.99 (.77)	.17, .49	.33***	2.25 (.61)	.14, .46	.30***
Fearful faces < Shapes	-.89 (.57)	-.25, .03	-.11	-1.19 (.47)	-.32, -.05	-.18**
Angry faces < Shapes	.62 (.97)	-.08, .18	.05	-.21 (.68)	-.14, .10	-.02
Neutral faces < Shapes	-.11 (1.05)	-.17, .16	-.01	.91 (.86)	-.08, .23	.07

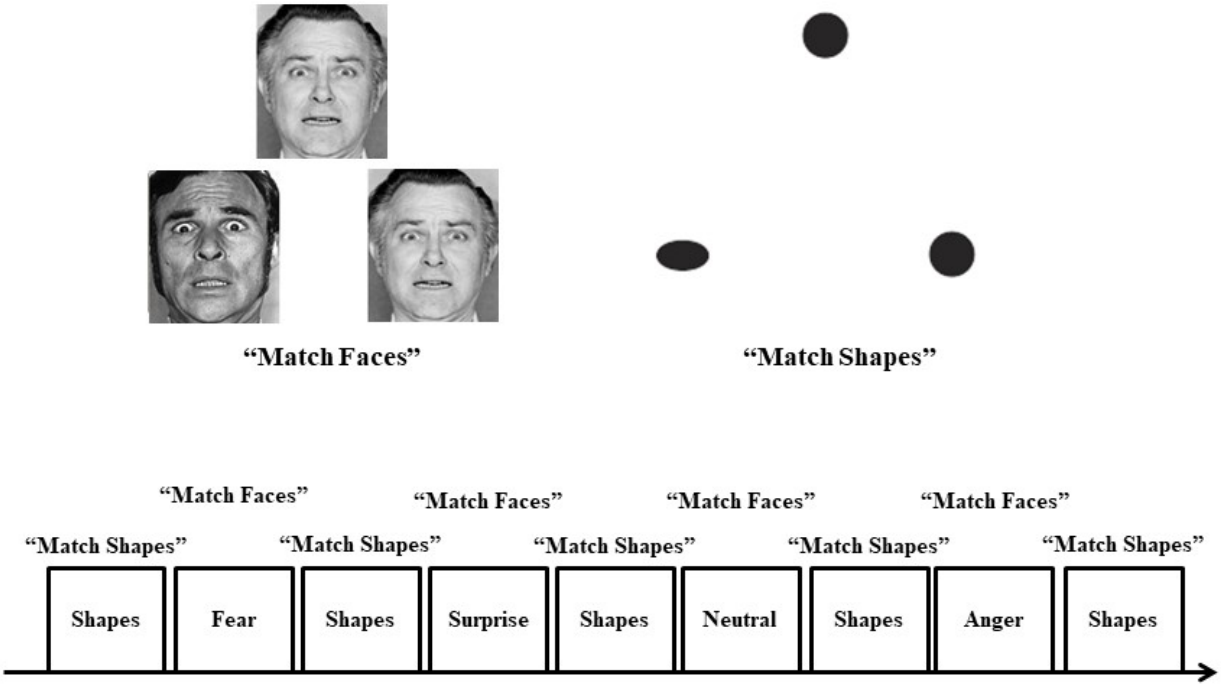
Note. ***$p < .001$, **$p < .01$, *$p < .05$, †$p < .05$. We examined a multivariate SEM where we regressed SRP psychopathy factor scores at age 22 onto predictors at age 20, while accounting for the covariance of predictors and factor scores. Model 1 includes only race and income as covariates (model fit statistics: χ^2=4.16, df=4, CFI=.999, TLI=.997, RMSEA=.02, SRMR=.03). Model 2 includes race, income, and earlier antisocial behavior and CU traits at age 20 (model fit statistics: χ^2=6.57, df=6, CFI=.997, TLI=.992, RMSEA=.02, SRMR=.03). Over and above the continuity of antisocial behavior and CU traits with later psychopathy, weakened amygdala-vmPFC functional connectivity during the processing of fearful faces < shapes at age 20 (but not neutral faces < shapes or angry faces < shapes) was related to higher Factor 2 psychopathy scores at age 22. However, after testing whether the bootstrapped confidence intervals overlapped by more or less than 50% (Cumming, 2009), we found no significant differences in the estimates for the pathway from fearful face < shapes to Factor 1 vs. Factor scores in either Model 1 or Model 2.

Supplemental Table 6. The relationship between amygdala-vmPFC functional connectivity to fearful faces and later psychopathic traits is driven by impulsive-lifestyle and antisocial behaviors, but not interpersonal or affective personality traits.

	Correlated outcomes (four facet scores of psychopathy at age 22)							
	Interpersonal traits		**Affective traits**		**Impulsive-lifestyle traits**		**Antisocial traits**	
Model 1: Only race and income as covariates	B (SE)	β	B (SE)	β	B (SE)	β	B (SE)	β
Race	.11 (.08)	.11†	.17 (.08)	.17*	-.13 (.08)	-.13	.11 (.08)	.11
Monthly income ($)	-.12 (.06)	-.12	-.03 (.07)	-.03	.03 (.06)	.03	-.11 (.06)	-.11
Fearful faces < Shapes	-.10 (.08)	-.10	-.11 (.07)	-.11	-.17 (.08)	-.17*	-.14 (.07)	-.14*
Angry faces < Shapes	.01 (.08)	.01	-.05 (.08)	-.05	-.07 (.07)	-.07	-.09 (.08)	-.09
Neutral faces < Shapes	-.06 (.09)	-.06	-.02 (.09)	-.02	.001 (.09)	.001	.08 (.08)	.08
Model 2: Race and income, and earlier antisocial behavior and CU traits as covariates	B (SE)	β	B (SE)	β	B (SE)	β	B (SE)	β
Race	.89 (.66)	.09	1.37 (.66)	.15*	1.26 (.63)	-.14*	.68 (.52)	.09
Monthly income ($)	-.36 (.16)	-.14*	-.12 (.17)	-.05	.002 (.13)	.001	-.25 (.09)	-.13**
Antisocial behavior (age 20)	.29 (.09)	.29***	.24 (.06)	.25***	.34 (.07)	.37***	.21 (.06)	.27***
CU traits (age 20)	1.45 (.40)	.29***	1.54 (.45)	.32***	1.11 (.38)	.24**	1.13 (.30)	.30***
Fearful faces < Shapes	-.44 (.34)	-.10	-.45 (.30)	-.11	-.72 (.32)	-.18*	-.47 (.24)	-.14*
Angry faces < Shapes	.53 (.55)	.07	.10 (.53)	.01	-.05 (.48)	-.01	-.16 (.36)	-.02
Neutral faces < Shapes	-.22 (.59)	-.03	.11 (.54)	.02	.15 (.53)	.02	.66 (.45)	.12

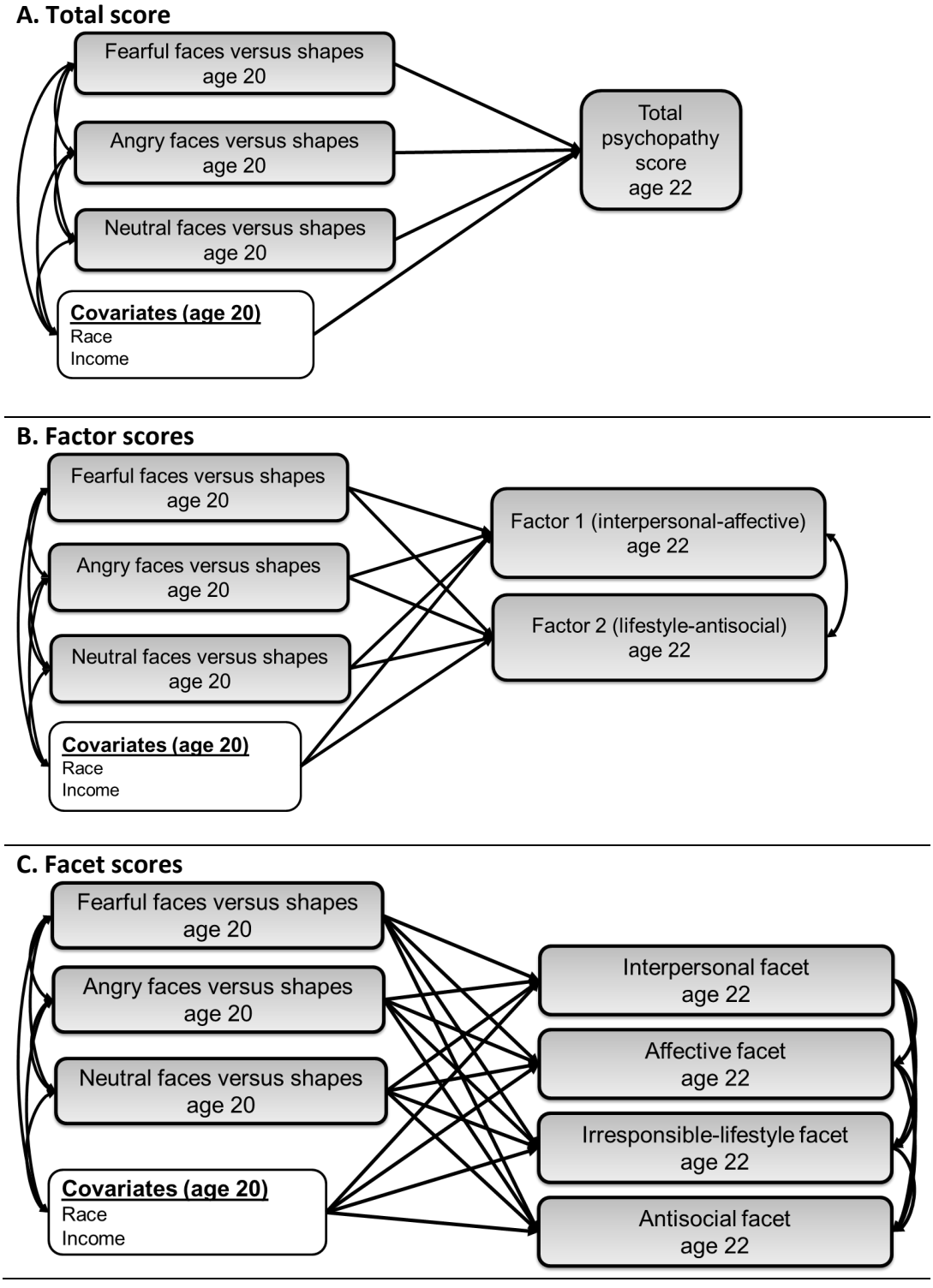
Note. ***$p < .001$, **$p < .01$, *$p < .05$, †$p < .05$. We examined a multivariate SEM where we regressed SRP psychopathy facet scores at age 22 onto predictors at age 20, while accounting for the covariance of predictors and outcomes. Model 1 includes only race and income as covariates (model fit statistics: χ^2=4.25, df=4, CFI=.999, TLI=.995, RMSEA=.02, SRMR=.03). Model 2 includes race, income, and earlier antisocial behavior and CU traits at age 20 (model fit statistics: χ^2=6.69, df=6, CFI=.998, TLI=.988, RMSEA=.03, SRMR=.03). Over and above the continuity of antisocial behavior and CU traits with later psychopathy, weakened amygdala-vmPFC functional connectivity during the processing of fearful faces < shapes (but not neutral faces < shapes or angry faces < shapes) at age 20 was specifically related to higher impulsive-lifestyle and antisocial facet scores of psychopathy at age 22.

Supplemental Figure 1. Emotional faces matching paradigm used to capture amygdala reactivity to faces (fearful faces pictured).



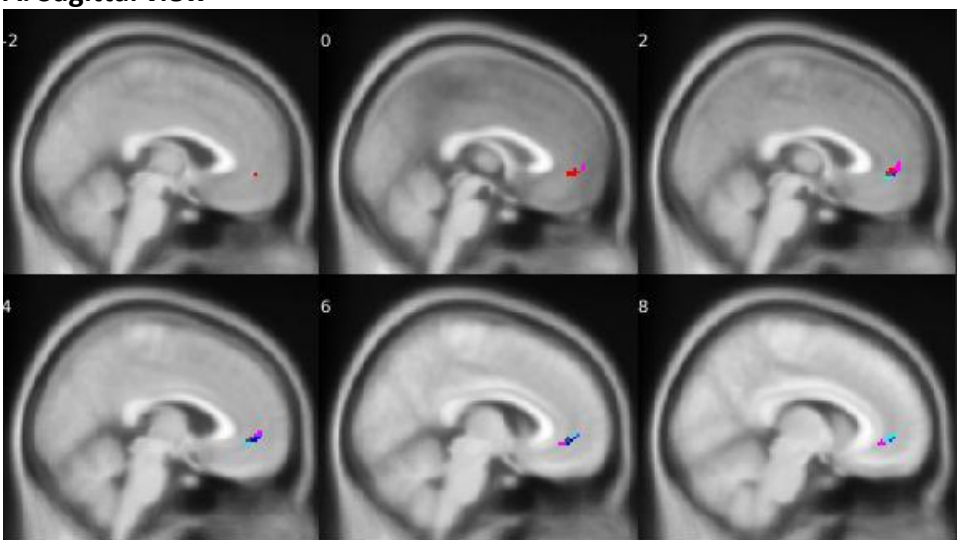
Note. Participants were randomly assigned to one of four counterbalanced versions of the task, which varied the order of the four perceptual face processing blocks (i.e., anger, fear, surprise, neutral). In the current study we focused on angry, fearful, and neutral facial expressions.

Supplemental Figure 2. Three models to test unique associations between amygdala-vmPFC functional connectivity during the processing of fearful, angry, and neutral faces relative to shapes and total psychopathy scores, factor scores, and facet scores.

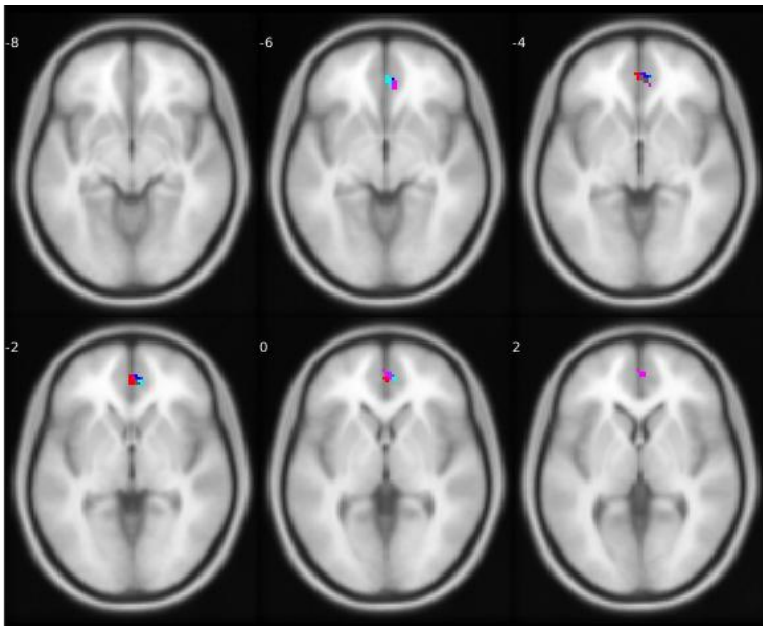


Supplemental Figure 3. Significantly greater negative connectivity between the amygdala and vmPFC during the processing of fearful faces versus shapes, angry faces versus shapes, and neutral faces versus shapes.

A. Sagittal view



B. Transverse view



Note. We used gPPI to examine functional connectivity of the amygdala seed region (not shown) with activation of the vmPFC (centered on x, y, z, = -2, 44, -4) during the processing of fearful faces versus shapes, angry faces versus shapes, and neutral faces versus shapes. Key: pink = right amygdala seed, fearful faces < shapes (8,40,-6), t = 4.33, k = 31; red = left amygdala seed, fearful faces < shapes (2,48,-2), t = 4.22, k = 29; light green = right amygdala seed, angry faces < shapes (2,44,4), t = 3.61, k = 25; dark green = left amygdala seed, angry faces < shapes (0,42,-4), t = 4.84, k = 152; light blue = right amygdala seed, neutral faces < shapes (8,48,-2) , t = 4.33, k = 38; dark blue = left amygdala seed, neutral faces < shapes (4,48,-4) , t = 3.93, k = 11. All clusters and peaks FWE-corrected within the vmPFC mask (see **Supplemental Table 2**).

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