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Granularity of Emotions in Brain and Behavior and Resilience to Childhood Violence Exposure

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ABSTRACT

BACKGROUND: This study identified behavioral and neural indices of the specificity of emotion representations in adolescents' brains and assessed their association with resilience to childhood violence exposure.

METHODS: Eighty 13- to 18-year-old adolescents with variable exposure to violence viewed emotion-eliciting videos and rated how angry, disgusted, sad, scared, and upset they felt. Sixty-nine participants viewed the same videos in the magnetic resonance imaging scanner, once while labeling their emotions and once while counting the number of people.

RESULTS: Emotion labeling (vs. counting) led to greater blood oxygen level–dependent activation in the medial and ventrolateral prefrontal cortex. Based on representational similarity analysis, if 2 stimuli elicited more similar patterns of activation within those brain regions, those stimuli had more similar emotion ratings, suggesting that encoding of emotion categories within these brain regions is reflected in their activation patterns. Moreover, emotion differentiation measured behaviorally and the mean neural dissimilarity across all stimulus pairs for each participant each moderated the association between violence exposure and psychopathology such that the association between violence exposure and psychopathology was weaker in individuals with greater emotion differentiation and neural dissimilarity.

CONCLUSIONS: The granularity of emotions reflected in adolescents' brains and behavior contributes to resilience and therefore may serve as a target for preventive interventions.

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Childhood violence exposure is common and is associated with increased risk for psychopathology, with onset frequently occurring in adolescence (1–3). Heightened sensitivity to stress is one pathway through which childhood adversity may increase mental health risk (4). Therefore, fostering skills that support coping with stress and distress may promote resilience to psychopathology among youth exposed to violence. Emotion differentiation is a skill that has consistently been found to support coping with psychosocial stress in the short term and contribute to well-being and resilience over time (5–8). In the current study, we evaluated the correspondence between behavioral and neural indices of how specifically emotions are represented in the brain and assessed whether these indices are associated with resilience to psychopathology among adolescents exposed to violence during childhood.

Emotion differentiation (i.e., granularity) is the specificity with which people experience and describe their own emotions. It is typically measured based on the degree of correlation between momentary reports of the intensity of various emotion labels to a given situation, either in response to a stimulus in a behavioral task (8) or in daily life (5). Greater differentiation of negative emotions is associated with more frequent and effective use of emotion regulation across strategy types, especially when regulating intense negative emotions (5,9), although not with the selection of more effective or adaptive emotion regulation strategies (9). Labeling of emotions (i.e., affect labeling) has also been conceptualized as a form of implicit emotion regulation (10). Therefore, having the capacity to label emotions with more specificity may contribute to more frequently and effectively implementing both implicit and explicit emotional regulation. This may explain why higher emotion differentiation has been found to buffer the effects of stressful experiences on mental health problems (7,8,11) and therefore may contribute to resilience among youth exposed to greater violence.

Differences in the structure and function of brain regions involved in emotion processing and introspection, including the amygdala, medial prefrontal cortex (mPFC), ventrolateral prefrontal cortex (vlPFC), temporoparietal junction (TPJ), and posterior cingulate cortex (PCC), likely underlie individual differences in emotion differentiation (12,13), and explicitly labeling emotions is associated with greater activation in the vlPFC and decreases in amygdala activation (14), potentially indicating a decrease in novelty and uncertainty around the meaning of affective cues when an emotion label is applied to them (15,16). However, while engagement of the mPFC, vlPFC, TPJ, and PCC are associated with recognizing one's own emotional states broadly, because emotion concepts are complex and distributed across the brain, successful identification of neural activity patterns that differentiate between discrete emotions has only been achieved consistently through multivariate techniques, including representational similarity analysis (RSA) (12,17–20). Representational similarity of neural activity within the mPFC, PCC, and TPJ predicts the specific emotion of stimuli across multiple modalities (17–20), such that the mutivoxel patterns of activity in these brain regions are more similar when participants report more similar emotional experiences. Therefore, individuals with greater emotional differentiation may demonstrate more diverse neural responses when experiencing and reflecting on their own emotions. In other words, greater representational dissimilarity of neural responses to emotions in these brain regions may reflect greater emotion differentiation and in turn contribute to resilience to childhood violence exposure.

In the current study, we investigated neural and behavioral indices of emotion differentiation and how they interact with childhood violence exposure to predict psychopathology in adolescence. We tested the following hypotheses: 1) engaging in emotion labeling would be associated with greater activation in the vlPFC, mPFC, TPJ, and PCC and reduced activation in the amygdala compared to viewing of affective stimuli while attending to nonemotional content; 2) behavioral measures of emotion differentiation would correspond with multivoxel representational similarity in brain regions activated during emotion labeling; 3) childhood violence exposure would be associated with greater psychopathology transdiagnostically; 4) emotion differentiation measured behaviorally would moderate the association between childhood violence exposure and psychopathology, such that this association would be weaker among adolescents who are higher in emotion differentiation; and 5) similarly, greater dissimilarity in the neural representation of emotions would moderate the association between childhood violence exposure and psychopathology, such that this association would be weaker among adolescents who have more dissimilar neural representations when viewing affective stimuli.

METHODS AND MATERIALS

Participants

The sample for this study comprises sixty-nine 13- to 18-year-old adolescents (41 female sex, mean [SD] age = 15.9 [1.56]). Six participants (all female sex) reported that their gender was nonbinary. Otherwise, gender was congruent with sex. Participants identified as the following races: Asian (n = 2, 4%), Black (n = 13, 19%), more than 1 race (n = 8, 12%), other (all indicated that they were Hispanic or Latinx, n = 4, 6%), or White (n = 41, 59%). Ten participants (14%) reported their ethnicity as Hispanic or Latinx.

Recruitment efforts targeted high-poverty schools and community organizations serving youth at increased risk for violence exposure in the Boston area. Exclusion criteria included nonfluency in English, presence of pervasive developmental disorders (e.g., autism), neurological disorder, and active safety concerns. Eighty participants participated in the study, but 8 did not complete the magnetic resonance imaging (MRI) due to either MRI contraindication or scheduling difficulties, 1 was excluded due to an acquisition error, and 2 were excluded because of motion artifacts.

Procedures

Participants completed an online session over Zoom, where they completed consent procedures with a parent. The parent was then asked to go to a different room, and parents and adolescents separately reported on exposure to violence and symptoms of psychopathology, and the participant completed the emotion differentiation task. Participants completed the emotion labeling functional MRI (fMRI) task at an in-person MRI session within a month of the Zoom session. All procedures complied with the Helsinki Declaration and were approved by the Harvard University Institutional Review Board.

Measures

Violence Exposure Severity. A violence exposure severity score was based on parent and adolescent reports of violence exposure on the UCLA Post-Traumatic Stress Disorder Reaction Index (PTSD-RI) (21), adolescent reports on the Childhood Experiences of Care and Abuse interview (22), the Violence Exposure Scale for Children, and the Childhood Trauma Questionnaire (23) and parent reports on the Juvenile Victimization Questionnaire (24). First, we standardized measures of 1) number of violence exposure types, 2) frequency of violence exposure, and 3) severity of physical or sexual abuse exposure and computed a mean z score. More details are provided in the Supplement. The construction of this composite was preregistered (https://osf.io/cpyzt), and this method of creating a threat composite has been used in previous studies [e.g., Weissman *et al.* (25)].

Transdiagnostic Psychopathology (p-Factor). Adolescents and their parent reported on symptoms of child psychopathology using the Children's Depression Inventory-2 to measure depressive symptoms (26), the Screen for Child Anxiety Related Emotional Disorders (27) to measure anxiety symptoms, and the PTSD-RI to measure posttraumatic stress disorder symptoms. Attention problems, rule-breaking behaviors, and aggressive behavior were assessed based on the Youth Self-Report and Child Behavior Checklist (28). Following previous work (29,30), we performed confirmatory factor analysis (CFA) to specify internalizing and externalizing latent factors and a higher-order general psychopathology latent factor (p). Justification of the use of p for general psychopathology, details on model fit of the CFA, and supplemental analyses using alternative operationalizations of psychopathology are provided in the Supplement.

Emotion Differentiation. Participants viewed 20 5-second video clips that had previously been found to elicit self-reported negative affect (31). A series of 5 emotion ratings—angry, disgusted, scared, sad, and upset—appeared sequentially under the video. An emotion differentiation score was computed as 1 minus the intraclass correlation coefficient (32). More details on this task are provided in the Supplement (Figure S1).

Emotion Labeling fMRI Task. Participants viewed the same 20 video clips as were used in the emotion differentiation task. In addition, 20 neutral video clips were used. During each trial, the 5-second videos played 3 times consecutively followed by a 3-second response period during which participants had to choose between 3 one-word responses. During emotion blocks, participants were instructed on a 2-second instruction screen to label the emotion that the video elicited in them in their head as they watched it and then choose the label that best fit. They selected 1 of 3 emotion labels. In the count and neutral conditions, they were instructed to count the number of people in the video and respond with either "1," "2," or "more than 2." These response options were meant to match the behavioral and attentional demands of the label condition while providing quantitative response categories that required minimal effort to discern, similar to conditions in similar tasks, such as labeling the gender of an emotional face (contrasted with labeling the emotion that the face was expressing) (14) or rating the width of the nose (contrasted with rating emotional intensity) (33). Between the response screen and the instruction screen for the next trial, a fixation cross was displayed for 5 seconds. Blood oxygen level–dependent (BOLD) activation when watching the emotional videos and mentally labeling their emotions versus counting the number of people was used to evaluate neural activation associated with emotion labeling. More details are provided in the Supplement.

fMRI Acquisition and Preprocessing. Scanning was performed on a 3T Siemens MAGNETOM Prisma scanner using a 32-channel head coil. T1-weighted magnetization-prepared rapid acquisition gradient-echo (MPRAGE) volumes were acquired (TR = 2200 ms, TE 1 = 1.57 ms, TE 2 = 3.39 ms, TE 3 = 5.21 ms, TE 4 = 7.03 ms, flip angle = 7°, FOV = 230 × 230 mm, 144 slices, in-plane voxel size = 1.2 mm^3). BOLD signal during functional runs was acquired using a gradient-echo T2*-weighted interleaved multiband echo planar imaging sequence (acceleration factor = 8). Seventy-two 2-mm thick slices were acquired parallel to the anterior commissure–posterior commissure line (TR = 800 ms, TE = 37 ms, flip angle = 52°, interslice gap = 0.6 mm, FOV = 208 mm). Prior to each scan, 4 images were acquired and discarded.

Preprocessing was performed using fMRIPrep version 20.1.1 (34). Boilerplate text appears in the Supplement. No spatial smoothing was applied. Following preprocessing, 2 participants were excluded from first-level analyses because motion censoring removed >20% of those participants' data.

Analyses

First-Level fMRI Analyses. Person-level models were fit using AFNI (Analysis of Functional Neuroimages) 3dDeconvolve (35). Boxcar functions were fit to each block of the task with 15-second durations. Nuisance regressors were included for motion in each of the 6 dimensions, the white matter, and the cerebrospinal fluid. The main contrasts of interest were BOLD activation when viewing affective videos and counting people versus when viewing neutral videos and counting people (i.e., emotional reactivity) and when viewing affective videos and labeling emotions versus when viewing affective videos and counting people (emotion labeling). This contrast was intended to compare conditions with similar attention demands while viewing the same stimulus, thereby isolating regions that were specific to the labeling of emotions. Models were also fit estimating separate coefficients for each of the 60 total blocks in the task to enable extraction of those coefficients at the voxel level for use in RSA.

Group-Level Univariate Contrasts. Group-level models were fit using AFNI's 3dttest++ with equitable thresholding and clustering (36) to identify regions with significantly greater activation during emotional reactivity and labeling (false-positive rate $<$ .05). These whole-brain analyses were restricted to gray-matter voxels as defined within AFNI's MNI template. Group-level significant activation clusters were used as regions of interest (ROIs) for RSA.

Representational Similarity Analysis. Within the regions involved in emotion labeling, regression coefficients were extracted from each voxel in the ROIs for each block in the emotion labeling condition. A correlation matrix was computed comparing each participants' voxelwise patterns of neural activity in response to every video in the emotion labeling condition to the pattern of neural activity in response to every other video (a 20 × 20 matrix made up of 190 total unique pairwise comparisons). A behavioral correlation matrix based on the emotion ratings in the emotion differentiation task was also created to compare the emotion ratings of each stimulus to every other stimulus for each participant. The mean correlations of neural activity and emotion ratings across all 69 participants were then computed for each of the 190 video pairs. The rank correlation (Kendall's tau-b) between the average correlation of the voxelwise neural patterns for each stimulus pair and the average correlation of the emotion ratings for each stimulus pair were computed and compared to chance (Kendall's tau = 0) with a Wilcoxon test. Kendell's tau was selected as a clearly interpretable, nonparametric measure for a "correlation of correlations" (37) where the precise estimate might not be as meaningful as how the correlations rank relative to the other pairwise comparisons. Finally, the mean correlation of neural activity across all 190 video pairs was computed for each participant. A measure of neural dissimilarity was then calculated as 1 minus the mean correlation. This analytic approach was preregistered at https://osf.io/cpyzt.

Between-Subjects Analyses. Linear regression in R version 4.0.0 was then used to examine 1) the relationship between childhood violence exposure severity and psychopathology (analysis preregistered at https://osf.io/xjmeb), 2) the interaction between childhood violence exposure severity and emotion differentiation in relation to psychopathology (exploratory analysis), and 3) the interaction of violence exposure severity and neural similarity during emotion labeling in relation to psychopathology (exploratory analysis). Participant age and sex were included as covariates in all analyses.

RESULTS

Descriptive statistics and intercorrelations among study variables are summarized in Table 1.

Group-Level Univariate Contrasts

The left mPFC (superior frontal gyrus) and the left vlPFC (inferior frontal gyrus) demonstrated significant activation when

Table 1. Descriptive Statistics and Intercorrelations

	n (%) or Mean (SD)	Range	Cohen's d	Correlation						
			1	2	3	4	5	6	7	8
1 Sex, Female	41 (59.4%)	–	–	–	–	–	–	–	–	–
2 Age, Years	15.9 (1.56)	13.0 to 18.9	0.036	–	–	–	–	–	–	–
3 Income-to Needs Ratio	5.04 (2.42)	0.32 to 9.28	0.092	0.156	–	–	–	–	–	–
4 Violence Exposure	−0.03 (0.86)	−0.71 to 3.85	0.219	0.158	−0.198	–	–	–	–	–
5 Emotion Differentiation	0.62 (0.17)	0.31 to 1.07	−0.448	0.172	0.132	0.121	–	–	–	–
6 Neural Dissimilarity	0.934 (0.053)	0.797 to 1.005	0.176	0.089	−0.192	−0.030	0.168	–	–	–
7 Internalizing Problems	−0.2 (11.6)	−16.0 to 33.6	1.121*	0.013	−0.061	0.426*	−0.051	−0.008	–	–
8 Externalizing Problems	−0.15 (2.58)	−4.50 to 7.77	0.805*	−0.037	−0.088	0.423*	0.026	−0.030	0.727*	–
9 General Psychopathology	−0.04 (0.82)	−1.42 to 2.36	0.898*	−0.029	−0.087	0.441*	0.013	−0.028	0.805*	0.992*

Cohen's *d* is provided for all variables in relation to sex. All other bivariate associations are correlations.
*$p < .05$.

participants were watching videos with negative emotional content and labeling their own emotions (Table 2; Figure 1).

Representational Similarity Analysis

A correlation matrix was created for each participant comparing BOLD activation across the 1605 voxels that were more active during the emotion labeling than the count condition on average. Voxelwise activation to each of the videos in the emotion labeling was correlated with voxelwise activation in each of the other videos. This led to 190 pairwise comparisons of the similarity of neural activation between every possible combination of 2 videos. Correlations ranged from $r = -0.71$ to $r = 0.82$ across all pairwise comparisons and participants. The mean correlation was then computed for each pairwise comparison across participants. These mean correlations ranged from −0.005 to 0.183 (Figure 2A).

A parallel correlation matrix was created for each participant comparing their 5 emotion ratings for each video to the emotion ratings to every other video during the emotion differentiation task. This led to 190 pairwise comparisons of the similarity of emotion ratings between every possible combination of 2 videos. Correlations ranged from $r = -1$ to $r = 1$ across all pairwise comparisons and participants. The mean correlation was then computed for each pairwise comparison across participants. These mean correlations ranged from −0.482 to 0.741 (Figure 2B).

The rank correlation (Kendall's tau-b) between the average correlation of the voxelwise neural patterns for each stimulus pair and the average correlation of the emotion ratings for each

Table 2. Results of Whole-Brain Univariate Contrast Analyses

Voxels	Peak, x, y, z	Region	Peak Voxel z Score
Negative Videos > Neutral Videos (Count)			
14,755	−10, −84, 45	Precuneus	6.21
1868	1, −88, −4	Lingual gyrus	6.64
1352	−2, 59, −35	Left/right superior frontal gyrus	3.63
561	−20, 58, 34	Left superior frontal gyrus	4.35
275	−48, 20, −4	Left inferior frontal gyrus	3.37
Neutral Videos > Negative Videos (Count)			
609	−48, −42, 61	Left inferior parietal lobule	3.74
599	55, −26, 57	Right postcentral gyrus	4.79
584	−66, −18, 12	Left transverse temporal gyrus	4.13
389	38, −16, 20	Right insula	5.06
260	28, −98, −2	Right middle occipital gyrus	5.32
Negative Videos: Label > Count			
971	−8, 55, 43	Left superior frontal gyrus	4.10
634	−54, 17, −2	Left inferior frontal gyrus	4.25
Negative Videos: Count > Label			
13,198	47, −52, 57	Right inferior parietal lobule	6.01
4919	30, 8, 66	Right middle frontal gyrus	6.50
913	64, −52, −4	Right middle temporal gyrus	5.35
471	4, 24, 48	Right medial frontal gyrus	4.95
391	−60, −50, −14	Left middle temporal gyrus	5.11

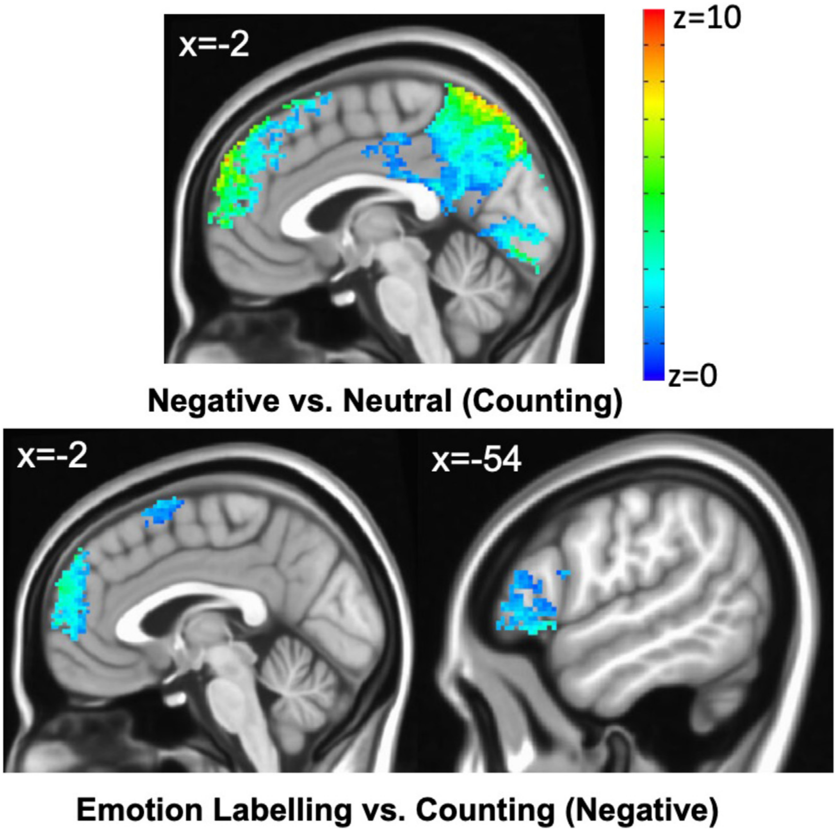

Figure 1. Results of whole-brain univariate analyses. Visualization of regions that were significantly more active when participants were viewing videos with negative emotional vs. neutral content, while counting the number of people in the video (top) and when viewing videos with negative emotion content and labeling their emotions vs. viewing the same negative videos and counting the number of people (bottom).

stimulus pair was significantly greater than chance (τ-b = 0.13, p = .009) (Figure 2C), suggesting a correspondence between the similarity of neural responses to negative emotion-eliciting videos and the similarity of subjective emotion ratings of those same videos. Parallel analyses using Euclidean distance as a measure of neural and behavioral similarity yielded similar results (see the Supplement).

Between-Subjects Analyses

More severe violence exposure was significantly associated with greater general psychopathology (B = 0.495, SE = 0.098, β = 0.487, $p < .001$). No direct significant associations were observed between violence exposure and either emotion differentiation or neural dissimilarity or between emotion differentiation or neural dissimilarity and general psychopathology (Table 1). Emotion differentiation and violence exposure significantly interacted to predict general psychopathology ($B = -1.34$, SE = 0.640, $\beta = -0.199$, p = .040) (Table 3), such that the association between violence exposure and psychopathology was weaker among adolescents with greater emotion differentiation (Figure 3). Similarly, neural dissimilarity and violence exposure significantly interacted in relation to general psychopathology ($B = -3.93$, SE = 1.67, $\beta = -0.233$, p = .022) (Table 3), such that the association between violence exposure and psychopathology was weaker among adolescents with more dissimilar neural responses to emotional stimuli (Figure 3). However, neural dissimilarity and emotion differentiation were not significantly correlated (r = 0.17, p = .168).

DISCUSSION

This study combined behavioral assessment with a novel fMRI task to evaluate the correspondence between neural and behavioral indices of the specificity of emotion representations in adolescents' brains and the role of these indices in resilience to the impacts of childhood violence exposure on mental health during adolescence. Adolescents demonstrated greater activation in the mPFC and vlPFC while viewing emotion-eliciting videos and labeling their own emotions. If 2 videos elicited more similar patterns of BOLD activation within the mPFC and vlPFC, they were more likely to be perceived as more similar on 5 emotion ratings, suggesting—as hypothesized—that some encoding of subjective emotion categories is occurring within these brain regions. Furthermore, also consistent with hypotheses, both greater emotion differentiation and the more dissimilar patterns of BOLD activation across all possible pairs of stimuli for each participant moderated the positive association between childhood violence exposure and general psychopathology in adolescence, such that the significant association between violence exposure and greater psychopathology was weaker among adolescents with higher emotion differentiation and those with more distinct patterns of neural activity across emotion stimuli. This suggests that constructing more granular emotion categories and representing emotional stimuli in the brain with more distinct patterns of neural activity may contribute to resilience to violence exposure.

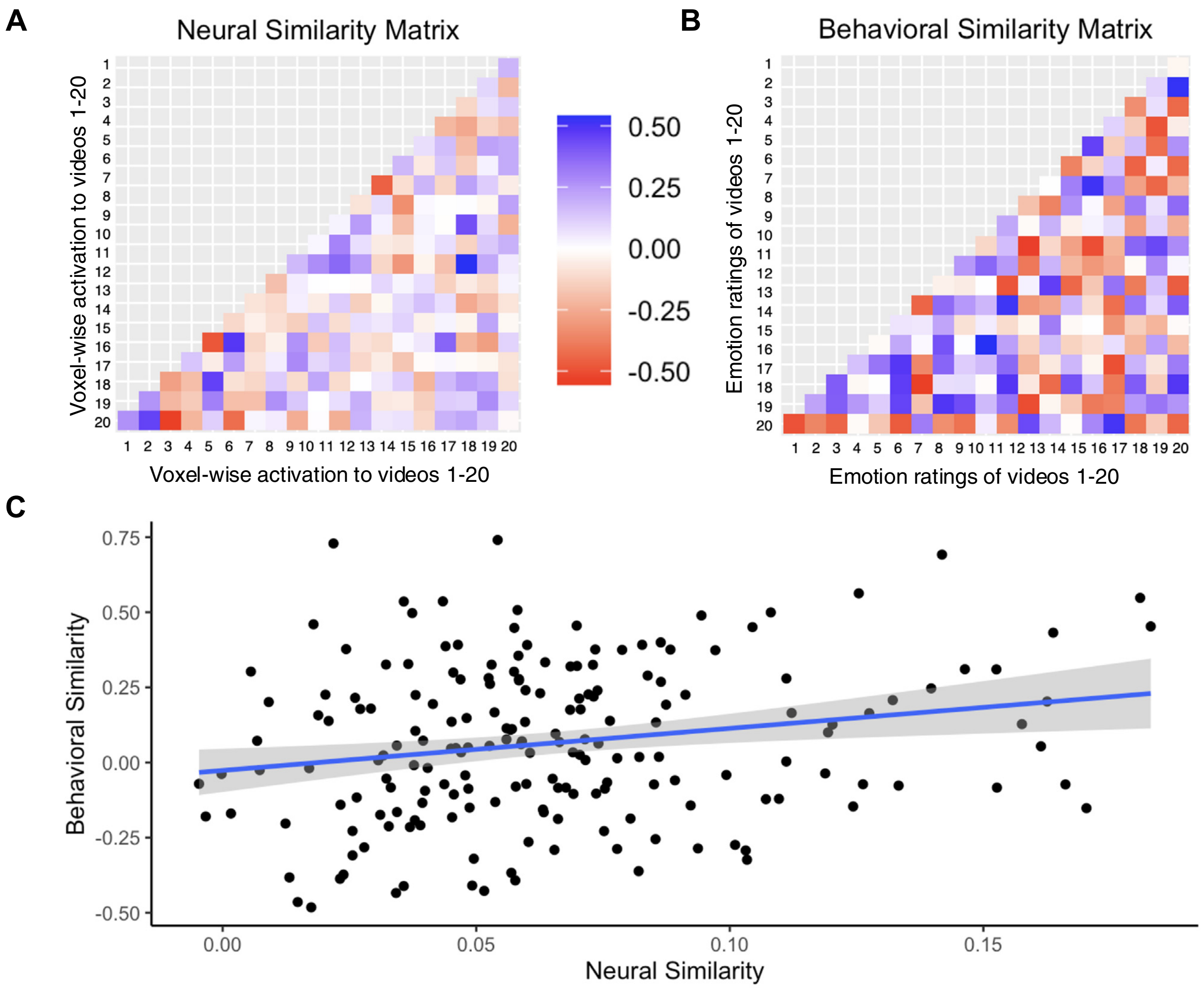

Figure 2. Results of representational similarity analysis. **(A)** Correlation matrix of voxelwise blood oxygen level–dependent response across voxels in the medial prefrontal cortex and ventrolateral prefrontal cortex to each of the 20 emotional stimuli compared to each of the other stimuli; **(B)** correlation matrix of participant ratings of "angry," "disgusted," "scared," "sad," and "upset" to each of the 20 emotional stimuli compared to each of the other stimuli; **(C)** association between the average correlation of the voxelwise neural patterns for each stimulus pair and the average correlation of the emotion ratings for each pair. The rank correlation (Kendall's tau-b) was significantly greater than chance (τ-b = 0.13, p = .009).

The similarity of patterns of BOLD activation within the mPFC and vlPFC when viewing 2 emotional stimuli corresponded with the similarity of the emotion ratings of those 2 stimuli. This suggests that the patterns of BOLD activation within the mPFC and vlPFC reflect experienced emotion categories to some degree. These results conceptually replicate findings in adults using a similar analytic approach (20), demonstrating that the representational similarity of both abstract features of events described in emotion-related vignettes and ratings of basic emotions in response to those same events corresponded with neural representational similarity within the mPFC (as well as the TPJ). According to the theory of constructed emotion, an emotion, like all mental events, is an ensemble of predictions that begin as patterns of neural activity to anticipate the needs of the body and attempt to meet those needs before they arise (15,38). These patterns of neural activity would be expected to be more similar when 2 situations are perceived to share more abstract features, which would in turn correspond with more similar emotion ratings (20). This is, in fact, what our results suggest. However, contrary to our hypotheses, emotion labeling of negative videos was not associated with greater activation in the PCC or TPJ or reduced activation in the amygdala. In fact, the negative videos elicited widespread, robust activation in the posterior default mode network, including the TPJ and PCC, especially when participants were instructed to attend to the number of people, but there were not significant differences in activation in the amygdala. Therefore, it seems that compared to the static face stimuli that were used in other emotion labeling fMRI paradigms (14), our dynamic emotion videos elicit greater

Table 3. Results of Between-Person Regression Analyses

	General Psychopathology			
Predictors	*B*	SE	β	*p* Value
Model 1: Emotion Differentiation as Moderator				
Age	−0.0311	0.0538	−0.056	.565
Sex, Female	0.492	0.170	0.275	.005
VE	0.526	0.098	0.518	<.001
ED	−0.168	0.491	−0.034	.732
VE × ED	−1.34	0.640	−0.199	.040
Observations	80			
R^2/Adjusted R^2	0.363/0.320			
Model 2: Neural Dissimilarity as Moderator				
Age	−0.0427	0.0529	−0.081	.422
Sex, Female	0.595	0.165	0.358	<.001
VE	0.423	0.097	0.441	<.001
ND	−0.475	1.54	−0.031	.759
VE × ND	−3.93	1.67	−0.233	.022
Observations	69			
R^2/Adjusted R^2	0.392/0.343			

ED, emotion differentiation; ND, neural dissimilarity; VE, violence exposure.

socioemotional processing regardless of engagement in explicit emotion labeling but are not as reliable at eliciting acute signals of uncertainty or negative arousal from the amygdala or the salience network as we predicted in our preregistration (https://osf.io/cpyzt). Therefore, our results do not clearly inform the conceptualization of affect labeling as a form of implicit emotion regulation (10).

The findings that both emotion differentiation and neural dissimilarity moderate the association between violence exposure and psychopathology conceptually replicate and extend findings that youth with more granular representations of negative emotions develop fewer internalizing problems following stressful life events (7,8,11). Moreover, our results suggest that more diverse neural encoding of affective information is also associated with resilience to the mental health impacts of violence exposure. Emotion differentiation, which is a teachable skill, may therefore be a feature of the adolescent brain, observable in both its function and in subjective emotion ratings that contributes to resilience in the face of stress and represents a potential target for interventions that are aimed at preventing psychopathology.

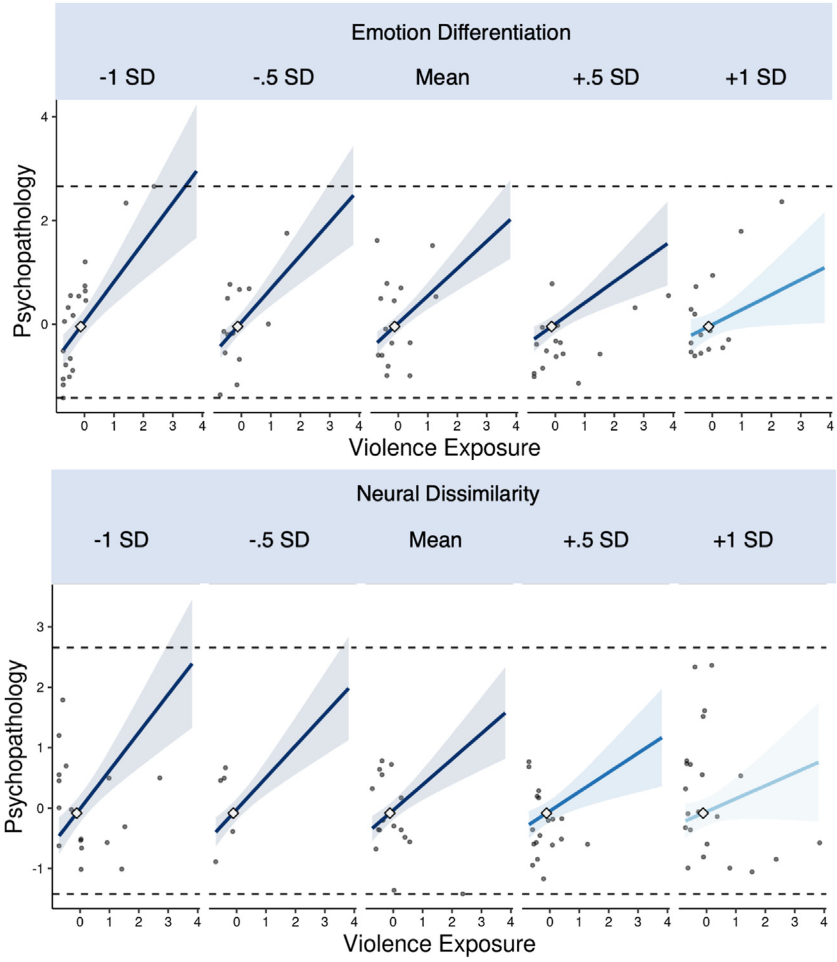

Figure 3. Significant moderation of the association between violence exposure and psychopathology by both emotion differentiation and neural dissimilarity. Emotion differentiation and violence exposure significantly interacted in relation to general psychopathology such that the association between violence exposure and psychopathology was weaker among adolescents with greater emotion differentiation. Neural dissimilarity and violence exposure significantly interacted in relation to general psychopathology such that the association between violence exposure and psychopathology was weaker among adolescents with more dissimilar neural responses to emotional stimuli on average. [Created with InterActive (https://connorjmccabe.shinyapps.io/interactive/) (51).]

Previous work suggests some developmental characteristics that may contribute to the development of greater emotion differentiation. First, emotion differentiation tends to decrease from childhood into early adolescence before increasing again as adolescents navigate the transition into experiencing and labeling mixed emotional states (32). Next, exposure to and learning of a greater emotion vocabulary supports the differentiation of emotion categories across development (39). Conversely, if children's early experiences with a caregiver are inconsistent, or if they are not exposed to as much as much emotion language or scaffolding of emotional experiences, they may represent emotion concepts in their brains and experience them less granularly (40–44). Additionally, school-based social emotional learning curriculums and effective mental health interventions such as cognitive behavioral therapy target skills in emotion labeling and focused attention that may support emotion differentiation, particularly among early adolescents, who are in a period of transition in their emotion differentiation.

Emotion differentiation and neural dissimilarity were moderators but not mediators of the association between violence exposure and psychopathology. There were no significant bivariate associations between emotion differentiation or neural dissimilarity and either violence exposure or psychopathology. This may reflect that other characteristics of the developmental environment such as the early language environment and scaffolding of emotional experiences by caregivers, teachers, or other adults, which impact the developing brain in ways that are distinct from exposure to violence (45,46), have a more direct influence on emotion differentiation than violence exposure. Furthermore, the protective influence of emotion differentiation on mental health may be to some degree conditional on the presence of significant life stress or adversity, which may require higher emotion differentiation to navigate adaptively. This is consistent with past work suggesting that the association between emotion differentiation and psychopathology is less pronounced if not totally absent when adolescents' stress levels are low (7,8).

The similar moderating effects of neural dissimilarity and emotion differentiation were present despite the finding that at the between-subjects level, they were only weakly, and not significantly, correlated with each other. This low correspondence challenges whether these measures capture equivalent processes. Neural dissimilarity between the videos, even in brain regions associated with emotion labeling, may also reflect differences in the neural representations of nonaffective characteristics of those videos. Meanwhile, the provision of only 5 emotion categories on the emotion differentiation task may limit its capacity to capture the full range of adolescents' emotion differentiation. These distinctions are reflected to some degree in the effect size of the within-person associations between the neural and behavioral similarity matrices. The magnitude of their correlation (τ-b = 0.13) was similar to the magnitude of the between-person correlation between neural dissimilarity and emotion differentiation (r = 0.17), but with 190 pairwise comparisons in the within-person analyses versus 80 participants in the between-person analyses, the statistical power to detect those within-person effects was considerably greater. Thus, neural dissimilarity and emotion differentiation may capture relatively distinct individual differences in the granularity with which emotion categories are represented in the adolescent brain, both of which may contribute to resilience to violence exposure.

Despite the novelty of our approach in this study and its potential for generating testable hypotheses for future work, the sample size warrants cautious interpretation. While the number of trials and pairwise comparisons make these data suitable for within-person analyses, the sample size is quite small for analyses of individual differences (47,48). The use of a task-based fMRI and a multivariate method (RSA) likely increase the reliability and potential effect size compared to a typical brain-wide association study (48,49), but the sample size nonetheless warrants a cautious interpretation of the findings. Moreover, we are underpowered to detect moderation overall, suggesting both that these are meaningful effect sizes but also that they warrant replication in larger samples. Finally, the design of our fMRI task was limited because the interval between when videos were shown was only 10 seconds. While this should lead to only minimal convolution of the 15-second duration boxcar functions, and task conditions were presented in a random order, at least 2 more seconds would have been preferable and consistent with typical recommendations for block designs (50).

Conclusions

The results of the current study suggest that some encoding of subjective emotion categories occur within the mPFC and vlPFC, as reflected in their patterns of BOLD activation, and that constructing more granular emotion categories and representing them with more distinct patterns of neural activity contributes to psychological resilience to childhood violence exposure. Emotion differentiation, which is a teachable skill, may therefore be a feature of the adolescent brain that contributes to resilience in the face of stress and represents a potential target for interventions aimed at preventing psychopathology.

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The data and analytic code underlying this article are available on Open Science Framework at https://osf.io/qem7s.

The authors report no biomedical financial interests or potential conflicts of interest.

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