



Exposure to violence and low family income are associated with heightened amygdala responsiveness to threat among adolescents

Stuart F. White^{a,*}, Joel L. Voss^b, Jessica J. Chiang^c, Lei Wang^b, Katie A. McLaughlin^d, Gregory E. Miller^c

^a Boys Town National Research Hospital, 14100 Crawford Street, Boys Town, NE, 68010, United States

^b Feinberg School of Medicine, Northwestern University, 303 E. Chicago Avenue, Chicago, IL 60611, United States

^c Institute for Policy Research and Department of Psychology, Northwestern University, 2029 Sheridan Road, Evanston, IL, 60208, United States

^d Department of Psychology, Harvard University, 33 Kirkland St. Cambridge, MA, 02138, United States

ARTICLE INFO

Keywords:

Socio-economic status
Threat
Anger
Amygdala
Violence

ABSTRACT

The processing of emotional facial expressions is important for social functioning and is influenced by environmental factors, including early environmental experiences. Low socio-economic status (SES) is associated with greater exposure to uncontrollable stressors, including violence, as well as deprivation, defined as a lack or decreased complexity of expected environmental input. The current study examined amygdala and fusiform gyrus response to facial expressions in 207 early adolescents (mean age = 13.93 years, 63.3% female). Participants viewed faces displaying varying intensities of angry and happy faces during functional MRI. SES was assessed using the income-to-needs ratio (INR) and a measure of subjective social status. Cumulative exposure to violence was also assessed. When considered in isolation, only violence exposure was associated with heightened amygdala response to angry faces. When considered jointly, violence exposure and lower INR were both associated with increased amygdala response to angry faces and interacted, such that lower INR was associated with increased amygdala reactivity to anger only in those youth reporting no exposure to violence. This pattern of findings raises the possibility that greater amygdala reactivity to threat cues in children raised in low-SES conditions may arise from different factors associated with an economically-deprived environment.

1. Introduction

Experimental work has demonstrated that individual differences in the processing of emotional facial expressions are related to social functioning (Hooker et al., 2006; Meffert et al., 2015; Rosen et al., 2018a,b,c) and psychopathology, including anxiety (Blackford and Pine, 2012), disruptive behavior (Blair, 2013), and depressive disorders (Kerestes et al., 2013). Neuroimaging research has begun to illuminate the neural mechanisms underpinning this type of social communication (for a review, see Blair, 2003) and implicates the amygdala (Pessoa and Adolphs, 2010) and lateral fusiform gyrus (Martin, 2007) in processing animate stimuli, including faces. Meta-analytic findings confirm that these regions are involved in the processing of facial expressions (Arsalidou et al., 2011). Emotional face processing reflects a process that is partially experience-dependent and that is impacted by variation in environmental experience during childhood and adolescence. Here, we examine how socio-economic status (SES) and related aspects of

children's experiences, including exposure to violence, relate to emotional face processing in early adolescence.

Conceptual models argue that exposure to violence alters emotional processing in ways that facilitate the rapid identification of environmental threat—an adaptive response to being raised in dangerous environments (McLaughlin et al., 2014; Sheridan & McLaughlin, 2014). Consistently, increased amygdala reactivity to threatening social stimuli has been consistently observed in violence exposed youth (McCrary et al., 2011; McLaughlin et al., 2015; Suzuki et al., 2014). Moreover, meta-analytic work has confirmed increased amygdala reactivity to threatening images in violence exposed youth (Hein and Monk, 2016), though this analysis included youth who had been neglected without exposure to violence. This suggests that negative emotional expressions are more salient to children who have experienced violence than those who have not.

Conceptually similar arguments have been advanced for children from families of low SES (Miller et al., 2011). Low-SES youth appear to

* Corresponding author at: Boys Town National Research Hospital, 14100 Crawford Street, Boys Town, NE, 68010, United States.

E-mail addresses: stuart.white@boystown.org (S.F. White), joel-voss@northwestern.edu (J.L. Voss), jessica.chiang@northwestern.edu (J.J. Chiang), leiwang1@northwestern.edu (L. Wang), kmclaughlin@fas.harvard.edu (K.A. McLaughlin), greg.miller@northwestern.edu (G.E. Miller).

<https://doi.org/10.1016/j.dcn.2019.100709>

Received 22 October 2018; Received in revised form 31 July 2019; Accepted 28 August 2019

Available online 18 September 2019

1878-9293/ © 2019 The Author(s). Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

develop an information-processing style where even ambiguous stimuli are interpreted as threatening (Chen and Matthews, 2003). It has been hypothesized that this may be due to greater than typical exposure to stressors that are uncontrollable. Uncontrollable stressors include violence-exposure, but also non-violent stressors such as parental separation, family conflict, noise, crowding, food insecurity, and lack of secure access to other basic necessities like shelter, clothing, transportation, and heating (Evans, 2004; Evans and English, 2002). However, the relationship between SES and emotional face processing has not been extensively considered. Among college students retrospectively characterizing the social standing of their families of origin, lower standing was associated with greater amygdala reactivity to threatening faces (Gianaros et al., 2008). Similarly, young adults from lower SES backgrounds exhibited had greater amygdala responses to threat vs. happy faces (Javanbakht et al., 2015).

Low SES is also associated with an increased likelihood of experiencing deprivation, defined as a lack or decreased complexity of expected social and cognitive environmental inputs (McLaughlin and Sheridan, 2016; McLaughlin et al., 2014). Critically, the kinds of deprivation that are common for low-SES children (in countries with developed economies) largely involve the quantity and quality of social interactions with caregivers (Bradley and Corwyn, 2002; Bradley et al., 2001; Hackman et al., 2015; Romeo et al., 2018; Rosen et al., 2018a,b,c; Weisleder and Fernald, 2013). This suggests that early deprivation may also be related to aspects of face processing. Indeed, children exposed to severe forms of deprivation, such as institutional rearing and neglect, exhibit difficulty discriminating facial emotion (Hwa-Froelich et al., 2014; Pollak et al., 2000). It is possible that similar patterns will be observed in children from low-SES families. Consistent with this possibility, a recent study observed reduced fusiform gyrus activation during a working memory paradigm involving emotional faces among children from low-SES families; in this paradigm, reduced fusiform activation was associated with worse memory of facial expressions (Rosen et al., 2018a,b,c). The degree of cognitive stimulation in the home environment in childhood has also been linked to fusiform gyrus structure in adolescence (Avants et al., 2015).

Although existing evidence suggests that SES might influence the development of neural responses to facial emotion, existing research is based solely on studies of adults and the specific aspects of environmental experience that are associated with SES that may be driving this relationship remain unclear. Accordingly, the current study had three goals. First, we sought to understand how children's SES relates to BOLD responses during a face-processing task. Second, recognizing that SES is a multidimensional construct, we considered two distinct components of SES. These components included the household's income-to-needs ratio, an objective indicator of material resources that is commonly used in the neurodevelopmental literature (e.g., Noble et al., 2015; Rosen et al., 2018a,b,c), as well as the family's subjective perception of their social standing. These objective and subjective dimensions of SES reflect different pathways through which SES might influence children's development and have been shown in multiple studies to be independently related to mental and physical health (Cohen et al., 2008; Goodman et al., 2001; McLaughlin et al., 2012). Third, we sought to examine how children's histories of violence exposure relate to BOLD responses during face-processing. Finally, recognizing that low-SES children, on average, have more exposure to violence (Sampson et al., 1997; Selner-O'Hagan et al., 1998), we examined an exploratory model including both violence exposure and SES to delineate their independent (and synergistic) associations with BOLD responses to facial emotion. This additionally allowed us to evaluate whether SES associations with neural response to facial emotion persist over and above the effects of violence exposure.

To address these questions, we recruited a large sample of eighth-grade youth, with high levels of ethnic, racial, and economic diversity, and had them complete a fMRI gender judgment paradigm involving faces displaying varying levels of angry expressions. Based on the

findings reviewed above (Gianaros et al., 2008; McCrory et al., 2017; Mogg and Bradley, 1998; Rosen et al., 2018a,b,c), we hypothesized that greater violence exposure and lower SES would be associated with increased amygdala response to angry faces. We also predicted that SES would be positively associated with responses in the lateral fusiform gyrus, given existing evidence for a link between deprivation and development of this region.

2. Methods

2.1. Participants

Participants were 277 youth recruited from the greater Chicago area through advertising, schools, and direct mail campaigns. Youth and a parent completed a phone screen to determine eligibility. Youth were eligible if they i) had no history of chronic medical or psychiatric illness; ii) were free of infectious diseases during the past two weeks, iii) were not taking any prescription medication during the prior three months, and iv) were not pregnant. Informed consent and assent were obtained from each participant family. The procedures in this study were approved by the Northwestern University Institutional Review Board.

2.2. Procedures

Eligible youth and one of their parents completed a laboratory visit, during which the parent completed interviews about the family's SES and youth completed psychosocial questionnaires and behavioral tasks. Youth completed an MRI scan at Northwestern University's Center for Translational Imaging on a separate day. Of the 277 youths enrolled in the study, useable MRI data was not available for 70 youth. Of these 70 youth, data was not collected for 40 youth due to i) technical problems (N = 11; computer/MRI problems), time constraints (N = 16, e.g., participant late arrival), refusal to scan (N = 8, e.g., scanner anxiety) and scheduling issues (N = 5, e.g., multiple canceled appointments). Data was not useable for 29 youth due to technical problems (N = 4, e.g., brain outside field-of-view) and movement (N = 25, defined as greater than 20% of TRs censored; see below for details). Exposure to violence data was not available for 1 participant. Thus, the final analytic sample was 207 youth. Demographic information for these 207 participants is displayed in Table 1.

2.3. Measures

2.3.1. History of chronic medical or psychiatric illness

Participant youth could not have a history of chronic medical or psychiatric illness. This was assessed initially via a phone-screen with parents. Youth were excluded if they had: i) any standing medication

Table 1
Participant Descriptive Statistics.

Gender	Number	Percentage
	131 females	63.3% female
<i>Racial/Ethnic Breakdown</i>		
European-American Youth (non-Hispanic)	92	44.44%
African-American	74	35.75%
Hispanic Youth	63	30.43%
Asian American	13	6.28%
Native American	5	2.42%
Hawaiian/Pacific Islander	2	0.97%
	Mean	Standard Deviation
Age	13.93	.55
Income-to-Needs Ratio	3.91	3.99
Exposure to Violence	0.93	1.20
Subjective Social Status	5.60	1.92

regimen in the previous 3 months, ii) a hospitalization in the previous 12 months, or iii) any history of pervasive developmental disorder. Moreover, at the initial lab visit, youth completed the brief Revised Child Anxiety and Depression Scale (Chorpita et al., 2000). Nine of the youth included in the sample endorsed clinically significant levels of anxiety and/or depression.

2.3.2. Socioeconomic status

Consistent with previous research (Luby et al., 2013; Noble et al., 2015, 2012), we used the income-to-needs ratio (INR) to characterize the SES of children in the study. During the laboratory visit, a parent or guardian reported on all sources of household income during the previous calendar year, including wages, other income, social security, disability and unemployment benefits, worker's compensation, inheritances, and help from relatives. The parent also described the composition of the household, and the ages of any children and adolescence. Using this information, and the federal government's poverty threshold for the calendar year before the child enrolled in the study, we computed income-to-needs ratio for each participant. Higher scores indicate greater income relative to poverty. Participants INRs ranged from 0.095 to 34.54 with an average INR of 3.91 (SD = 3.99). The INR of participants covered a large range. As a rule of thumb, scores from 0 to 0.99 are below the poverty threshold, scores from 1.00 to 1.99 are lower income, 2.00 to 3.99 are considered middle income and 4.00 and greater are considered high income (U.S. Census Bureau, 2004). INR scores had skewness of 3.31 and kurtosis of 18.27, which is inconsistent with the assumption of a normal distribution (George and Mallery, 2016). To reduce the skewness and kurtosis of the data, a Rankit transformation (Bliss et al., 1956) was conducted on the INR scores. Post transformation skewness was reduced to -0.002 and kurtosis was reduced to -0.083.

To capture the subjective aspect of SES, we had each child's parent or guardian complete the MacArthur Scale of Subjective Social Status. Parents were shown an illustration of a 9-rung ladder and asked to place an X on the rung that reflected where they stood "at this time in their lives relative to other persons in the United States" with regard to income, education, and occupational standing. This measure has been extensively validated and is associated with health outcomes over and above the effects of income (Adler et al., 2000, 2007; Cohen et al., 2008; Operario et al., 2004).

2.3.3. Exposure to violence

Exposure to violence was measured with a validated self-report instrument (Thomson et al., 2002), which assesses whether the child has experienced and/or witnessed various types of violence, including being shot with a gun, attacked with a knife, and punched, kicked, or pushed in a fight (see Table 1). It also assessed whether the child's family and/or friends had been hurt or killed by violence. Personal exposure to serious violence was somewhat rare in this sample, with just 7 children reporting a history of gun or knife attacks. Accordingly, to maximize variability, we constructed a count variable reflecting the number of different experiences of violence each child reported. Participants' exposure to violence scores ranged from 0 to 6 with an average of 0.93 (SD = 1.20). Exposure to violence scores had acceptable skewness of 1.64, but kurtosis of 2.89, which is inconsistent with the assumption of a normal distribution (George and Mallery, 2016). To reduce the skewness and kurtosis of the data, a Rankit transformation (Bliss et al., 1956) was also conducted on the exposure to violence scores reducing skewness to 0.745 and kurtosis was reduced to -0.276.

2.3.4. The morphed faces fMRI task

The current paradigm used a modified version of the morphed faces task that has been used previously (Blair et al., 1999; Marsh et al., 2008). During MRI scanning (see below), participants saw a facial expression displayed for 2000 ms, followed by a blank screen for 1000 ms and a jittered inter-stimulus interval (500–2500 ms). Participants were

required to indicate, via button press, the gender of the face. The facial expression stimuli consisted of still photos of four male and four female actors drawn from a widely used stimulus set (Ekman and Friesen, 1976). For each actor, five angry and five happy images were shown at varying levels of intensity (20%, 40%, 60%, 80% and 100% of prototypical). Each image was displayed once in pseudo-random order. Eight trials were presented at each level of intensity for each expression (80 trials total) in a single run lasting 7 min and 21 s.

2.4. MRI parameters, preprocessing, and individual level analysis

Participants were scanned at the Center for Translational Imaging at Northwestern University using a Siemens Prisma 3 T scanner with a 64 phased-array head/neck coil. A total of 202 functional images were taken with a T2* weighted gradient echo planar imaging (EPI) sequence (repetition time = 2000 ms; echo time = 27 ms; 240 mm field of view; 94 × 94 matrix; 90° flip angle). Whole-brain coverage was obtained with 43 axial slices (voxel size 1.694 × 1.694 × 1.7 mm³). Structural imaging consisted of a high-resolution navigated multiecho magnetization prepared rapid acquisition gradient echo sequence (MPRAGE, TR = 2300 ms, TE = 1.86, 3.78; flip angle = 7°; FOV = 256 × 256; matrix = 320 × 320; 208 slices; voxel size = 0.8 mm³).

Functional MRI data were analyzed using Analysis of Functional Neuroimages (AFNI; Cox, 1996). Functional images were despiked and slice-time and motion corrected. The anatomical scan for each participant was registered to the base volume of their functional images and then warped to Talairach space (Talairach and Tournoux, 1988). Each volume of a participant's functional data was then aligned to this base volume and also warped to Talairach space. All volumes were re-sampled to 2 mm³. Functional images were spatially smoothed with a 6 mm full-width-half-maximum Gaussian kernel. The time series were then normalized by dividing the signal intensity of a voxel at each time-point by the mean signal intensity of that voxel for each run and multiplying the result by 100. The resultant regression coefficients representing a percentage of signal change from the mean.

The individual level model characterized BOLD response to both angry and happy faces parametrically (or amplitude) modulated by intensity of facial expression. In other words, BOLD response was multiplied by a factor corresponding to facial expression intensity (here, 20%, 40%, 60%, 80% and 100% of prototypical). This reveals brain regions showing BOLD activation that varies with the level of the modulator (here, expression intensity). Thus, regressors included in the model were the six motion regressors obtained in preprocessing (see above) and the following task regressors: indicator functions for the (i) angry faces; (ii) happy faces; (iii) angry faces multiplied by intensity of facial expression; and (iv) happy faces multiplied by intensity of facial expression. All regressors were convolved with a canonical hemodynamic response function from the onset of the face image onset to account for the slow hemodynamic response. Linear regression modeling was performed using the 10 regressors described above, plus regressors to model a third-order baseline drift function to correct for slow movement over the course of the scan. Additionally in this regression model, volumes showing 0.5 mm or greater movement from the previous volume were censored. This produced β coefficients and associated t statistics for each voxel and regressor.

2.5. fMRI data analysis: group analysis

Group analysis was conducted on the individual level coefficients for the angry faces modulated by morph level. The voxel-level correlation between modulated BOLD response to angry facial expressions and exposure to violence, INR and Ladder ratings were examined separately and simultaneously using AFNI's 3dMVM program for a total of four analyses. Consistent with our hypotheses, a region-of-interest (ROI) approach was taken, examining anatomically derived left and right amygdala and fusiform gyrus ROIs. The amygdala ROI was derived from the

Eickhoff-Zilles Architectonic Atlas 50% probability mask (Amunts et al., 2005), while the fusiform gyrus ROI was drawn from the AFNI TT Daemon Atlas (Talairach and Tournoux, 1988). In light of concerns within the neuroimaging literature regarding type I error (Eklund et al., 2016), the AFNI 3dClustSim autocorrelation function (-acf) and an initial threshold of $p = .002$ were used (Cox et al., 2017) to generate extent thresholds for a corrected p value of .05. This yielded small-volume corrected extent thresholds of $k = 3.2$ for the amygdala and $k = 8.8$ for fusiform gyrus. All reported results exceeded these thresholds. Post-hoc testing was conducted on the average BOLD response extracted from the significantly activated voxels within each ROI. For completeness, a whole-brain analysis was also conducted for both angry and happy faces and is included in the Supplemental Materials.

3. Results

3.1. Behavioral results

3.1.1. Zero-order correlations

Significant correlations between the predictor variables were observed. Exposure to violence was inversely associated with both INR [$r = -0.269$, $p < 0.001$] and subjective social status [$r = -0.169$, $p = 0.015$]. INR and subjective social status were positively associated [$r = 0.529$, $p < 0.001$].

3.1.2. Accuracy and response latency results

Participants were 90.94% (SD = 14.66) accurate for angry faces and 91.86% accurate (SD = 15.00) for happy faces. Participants had an average response time of 845.22 ms (SE = 120.04 ms) for angry faces and 835.10 ms (SE = 112.42 ms) for happy faces. Participants were significantly more accurate [$t = 2.97$, $p = .003$] and faster [$t = 2.36$, $p = .019$] when responding to happy relative to angry faces. No associations were found between INR, subjective social status, or exposure to violence and accuracy or response times for either happy or angry faces [$r^2 = -.086$ to $.062$, $p > .222$].

3.2. fMRI results

3.2.1. Amygdala

Exposure to violence, when entered alone, was significantly associated with increased modulated BOLD response to angry faces within the right amygdala [$k = 10$, $r = .265$, $p < .001$; see Table 2]. Neither

Table 2

Regions within Amygdala and Fusiform Gyrus Showing Significant Correlations with Exposure to Violence, Income, and Subject Social Status Considered Individually and Simultaneously.

Region	Left/ Right	Coordinates of Peak Activation ^a					Voxels	Cohen's <i>d</i>
		x	y	z	F	p		
<i>Amygdala</i>								
<u>Exposure to Violence</u>								
Right		25	-1	-22	13.32	0.0003	10	.550
<u>Fully-adjusted model</u>								
<u>Main Effect of Exposure to Violence</u>								
Right		25	-3	-21	15.50	0.0001	23	.539
<u>Main Effect of Income</u>								
Left		-24	-2	-10	13.13	0.0004	4	.423
<u>Exposure to Violence-by-Income Interaction</u>								
Left		-23	-7	-14	13.38	0.0003	14	.468
<i>Fusiform Gyrus</i>								
<u>Main Effect of Income</u>								
Right		45	-14	-27	18.81	< 0.0001	16	.592
<u>Main Effect of Subjective Social Status</u>								
Left		-35	-45	-18	16.82	< 0.0001	13	.577

Note.

^a Based on the Tournoux & Talairach standard brain template.

SES measure (i.e., INR nor subjective social status) was associated with modulated BOLD response in the amygdala when considered in isolation.

Exposure to violence, INR, and subjective social status were also considered simultaneously. In the fully-adjusted model, a significant positive association between exposure to violence and modulated BOLD responses was again observed within right amygdala after adjusting for both SES measures [$k = 23$, $r = .260$, $p = .003$; see Fig. 1 and Table 2]. A significant negative correlation was also observed between INR and modulated BOLD responses in the left amygdala [$k = 4$, $r = -0.207$, $p = .003$; see Table 2], such that lower income was associated with greater amygdala activation. Furthermore, a significant exposure to violence-by-INR interaction was observed in the left amygdala ($k = 14$), where a larger magnitude, negative association [Fisher's $Z = 2.99$, $p = 0.003$] was observed between INR and modulated BOLD response to angry faces in the youth with no exposure to violence [$r = -.336$] relative to youth who had been exposed to violence [$r = .073$]. In other words, lower income was associated with greater left amygdala response to angry faces in youth not exposed to violence (no endorsement of a violent experience), but INR was not associated with amygdala response in children who had experienced violence (endorsed ≥ 1 violent experience) Significant exposure to violence-by-ladder score, INR-by-ladder score and exposure to violence-by-ladder score-by-INR interactions were not observed in the amygdala.

3.2.2. Fusiform gyrus

When entered alone, higher INR was significantly associated with decreased modulated BOLD response to angry faces in an anterior region of the right fusiform gyrus [$k = 16$, $r = -0.284$, $p < .001$; see Table 2]. Subjective social status, when considered independently, was negatively associated with modulated BOLD response in a posterior region of left fusiform gyrus [$k = 13$, $r = -0.277$, $p < .001$; see Table 2]. Exposure to violence was not significantly associated with modulated BOLD response in fusiform gyrus when considered in isolation.

No significant main effects or interactions were observed within fusiform gyrus when exposure to violence, INR, and subjective social status were considered simultaneously.

3.3. Confounding factors

To ensure that the above findings were not due to the inclusion of the nine youth who endorsed clinically significant anxiety and/or depression, the analyses were re-conducted without these youth. In all regions, activations in proximal regions were observed albeit the exposure to violence-by-INR interaction observed in the left amygdala was attenuated [$p = .0023$]. See Supplemental Table 4.

4. Discussion

The current study sought to describe the associations between SES, violence exposure, and the processing of angry facial expressions in early adolescence. There were four main findings. First, violence exposure was positively associated with BOLD response in amygdala. Second, lower INR was not associated with increased BOLD response in amygdala when considered independently, but was negatively associated with amygdala response in a model controlling for violence exposure. Further, lower INR and lower subjective social status were also associated with increased BOLD response to angry facial expressions within fusiform gyrus. Third, when INR, subjective social status and violence exposure were considered simultaneously, violence exposure and lower INR were each significantly associated with increased amygdala responsiveness, and these main effects were qualified by an interaction between INR and violence exposure in the amygdala, such that the association between INR and amygdala activity was only observed in adolescents with no exposure to violence.

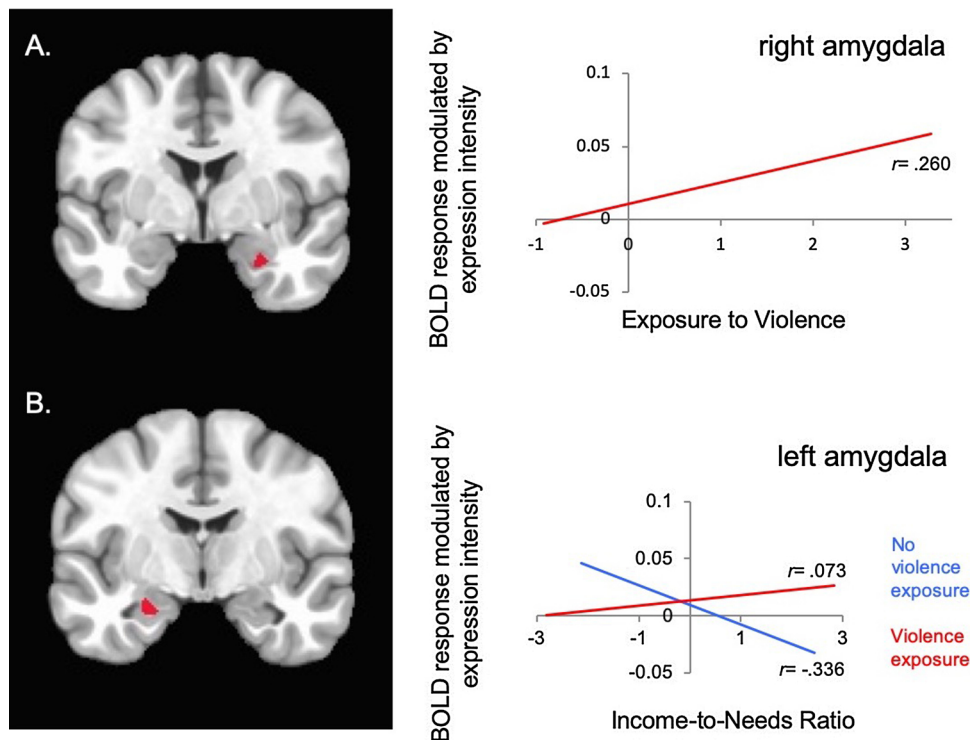


Fig. 1. Significant effects of exposure to violence and income-to-needs ratio within the amygdala. Increased amygdala responsiveness was associated with increased rankit transformed exposure to violence scores (A). The association between lower rankit transformed income-to-needs ratio scores and amygdala response was of larger magnitude in youth with no exposure to violence than in violence exposed youth.

Consistent with predictions, exposure to violence was significantly associated with increased amygdala responsiveness to angry faces. It has been argued that early exposure to violence alters emotional processing in ways that facilitate the rapid identification of threat in the environment and that these changes are adaptive in dangerous environments (McLaughlin et al., 2014; Sheridan & McLaughlin, 2014). Indeed, youth exposed to violence, relative to those not exposed to violence, perceive angry expressions at lower intensities (Pollak et al., 2009), at high rates in ambiguous stimuli (Ardizzi et al., 2015; Pollak and Sinha, 2002), and show attentional biases towards angry faces (Pollak and Tolley-Schell, 2003; Shackman and Pollak, 2014; Shackman et al., 2007). The amygdala is a structure that is critical in identifying threatening stimuli in the environment (Phelps and LeDoux, 2005) and angry facial expressions convey threat information (Oatley and Johnson-Laird, 1987). Consistent with the idea that exposure to violence is associated with neural changes that facilitate the rapid identification of threat, both previous research (Hein and Monk, 2016; McCrory et al., 2017; McLaughlin et al., 2015) and the current data indicate that violence exposure is associated with increased amygdala response to angry expressions.

Consistent with hypotheses, there was a negative association between income and amygdala response to angry faces; however, this relationship appeared to be driven by youth without a history of exposure to violence. This pattern of findings raises the possibility that greater amygdala reactivity to threat cues in children raised in low-SES conditions may arise from exposures besides violence. Extensive evidence demonstrates that low-income children, on average, experience more violence than their affluent peers (Evans and English, 2002). And as the findings here illustrate, violence exposure is positively associated with amygdala reactivity. However, the interaction between violence exposure and SES suggests that others factors associated with low SES may also influence amygdala reactivity. These could include differences in parenting, family conflict, parental separations, crowding, ambient noise, nutritional intake and pollutant exposure, and exposure to other uncontrollable stressors (i.e., insecure access to basic necessities like food, shelter, clothing, transportation, and heating; Evans and English, 2002). These potential explanations need to be studied in future

research.

Notably, the relationship between income-to-needs ratio and amygdala response to threat cues was seen youth with no exposure to violence. Because violence exposure was associated with amygdala reactivity independent of SES, these findings suggest that the relative contribution of exposure to violence to heightened amygdala reactivity is greater than the contribution of SES. In other words, high SES is not a protective factor in the presence of exposure to violence. Indeed, increased amygdala responses to threat cues following exposure to violence are seen in affluent populations (Dückers et al., 2016). However, this does not necessarily suggest that low-SES and exposure to violence do not interact in an additive fashion, even though this was not observed in the current study. More work will be required to fully disentangle the relationship between SES and amygdala response to threat cues and to fully explore the interactive relationship between SES, exposure to violence and amygdala response to threat cues.

Interestingly, the association between amygdala responsiveness and SES was restricted to income; no relationship between subjective social status and amygdala responsiveness was observed. Subjective social status is a relative indicator, which captures how people view their educational attainment, financial assets, and occupational prestige relative to others. While it has clear implications for health (Adler et al., 2000, 2007; Cohen et al., 2008; Operario et al., 2004), the current data suggest that subjective social status does not relate to threat processing like income or exposure to violence. These patterns suggest that factors that material assets, and the resources they provide access to, may have a stronger impact on neural processing of threat cues than relative social standing. However, additional work is needed to substantiate this conclusion.

Evidence suggests that extreme forms of deprivation, such as institutional rearing and neglect, are associated with disrupted expression recognition (Hwa-Froelich et al., 2014; Pollak et al., 2000) and processing (Parker et al., 2005). Moreover, children from low-SES families have shown reduced activation in fusiform gyrus during a working memory task (Rosen et al., 2018a,b,c). Contrary to these predictions, both lower income and subjective social status were associated with increased, not decreased, BOLD response in fusiform gyrus and these

findings did not remain significant after including violence exposure in the model. Importantly, prior studies finding associations of deprivation with ventral visual stream function have involved complex cognitive tasks that involve faces as stimuli, where activation of the fusiform has been directly related to task performance (e.g., Rosen et al., 2018a,b,c; Rosen et al., 2018a,b,c). It is possible that these types of differences emerge only in tasks that require a sustained representation of stimuli to be attended to for task performance, in contrast to the relatively simple gender discrimination required in the current study. This warrants greater examination in future research.

While low-SES environments are associated with reduced social interactions with care-givers (Bradley and Corwyn, 2002; Romeo et al., 2018; Weisleder and Fernald, 2013), it is unclear whether children in these environments actually see fewer angry expressions on individuals around them. Indeed, it seems plausible that angry expressions in low-SES contexts might be particularly common due to the high stress associated with low-SES environments. Children raised in these environments might not have the vocabulary to label facial expressions accurately (Hwa-Froelich et al., 2014; Pollak et al., 2000), but angry faces may remain highly salient cues. Indeed, this is consistent with data showing that youth exposed to violence exhibit attention biases toward angry faces and take longer to disengage from angry faces than children who have not experienced violence (Pollak and Tolley-Schell, 2003; Shackman and Pollak, 2014; Shackman et al., 2007). Thus, while deprivation associated with low-SES environments remains a research topic of importance, it may not be related to increased sensitivity to threat cues in the environment.

There are two important strengths of the current paper that are important to consider. First, this sample was very large for a neuroimaging study. Given the moderate effect sizes of the relationships between exposure to violence, SES and BOLD response, large samples will be needed to detect significant effects, particularly in small regions like the amygdala. Second, the sample was racially, ethnically, and economically diverse, and thus more closely representative of urban life in contemporary America relative to previous studies. Unlike other studies that have focused on samples exposed to severe, but uncommon environments (e.g., maltreatment, institutional rearing), the current study examines the impact of relatively common environments, making the results highly generalizable. It is also important to consider the results in light of several limitations. First, approximately 25% of participants were not included in the final analysis. While this is a fairly common level of attrition in neuroimaging in this age group, excluded youth were less likely to be European-American [$\chi^2 = 8.91, p = .003$] and had greater exposure to violence than included youth (see supplemental Table 1). Mitigating this limitation, the final sample remained ethnically and racially diverse and had a wide range of exposure to violence. Second, measures of exposure to violence relied solely on self-report and important nuance regarding exposure to violence, such as severity and chronicity, were not accounted for. Such nuance may have important implications for understanding the neural correlates of violence exposure. Finally, a complete mental health assessment was not performed on the youth and it is possible that psychiatric symptoms were driving the current findings. However, this limitation is mitigated by the fact that the results remained largely consistent even once the youth endorsing clinically significant anxiety and/or depression were excluded.

In summary, and consistent with previous findings, the current data link exposure to violence and increased responsiveness to threat. Notably, the data also suggest that low-SES, specifically low-income levels, is associated with an increased responsiveness to angry faces within the amygdala, but only in the absence of exposure to violence. These data suggest that aspects of low SES environments beyond exposure to violence, possibly including other uncontrollable stressors, may lead to increased sensitivity to threat cues. These data indicate a more in-depth exploration of the experience of low SES environments and how exposure to these factors interact with neural functioning.

Declaration of Competing Interest

None.

Acknowledgements

This work was supported by the United States National Institutes of Health in grants from the National Heart, Lung, and Blood Institute to G.E. Miller (HL122328) and the National Institute of Mental Health in a grant to S.F. White (MH110643).

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.dcn.2019.100709>.

References

- Adler, N.E., Epel, E.S., Castellazzo, G., Ickovics, J.R., 2000. Relationship of subjective and objective social status with psychological and physiological functioning: preliminary data in healthy white women. *Health Psychology* 19 (6), 586–592.
- Adler, N.E., Stewart, J., Psychosocial Working Group, 2007. The MacArthur scale of subjective social Status. *The Psychosocial Research Notebook*. MacArthur Foundation.
- Amunts, K., Kedo, O., Kindler, M., Pieperhoff, P., Mohlberg, H., Shah, N.J., et al., 2005. Cytoarchitectonic mapping of the human amygdala, hippocampal region and entorhinal cortex: intersubject variability and probability maps. *Anat Embryol (Berl)* 210 (5–6), 343–352. <https://doi.org/10.1007/s00429-005-0025-5>.
- Ardizzi, M., Martini, F., Umiltà, M.A., Evangelista, V., Ravera, R., Gallese, V., 2015. Impact of childhood maltreatment on the recognition of facial expressions of emotions. *PLoS One* 10 (10), e0141732. <https://doi.org/10.1371/journal.pone.0141732>.
- Arsalidou, M., Morris, D., Taylor, M.J., 2011. Converging evidence for the advantage of dynamic facial expressions. *Brain Topogr.* 24 (2), 149–163. <https://doi.org/10.1007/s10548-011-0171-4>.
- Avants, B.B., Hackman, D.A., Betancourt, L.M., Lawson, G.M., Hurt, H., Farah, M.J., 2015. Relation of Childhood Home Environment to Cortical Thickness in Late Adolescence: Specificity of Experience and Timing. *PLoS One* 10 (10), e0138217. <https://doi.org/10.1371/journal.pone.0138217>.
- Blackford, J.U., Pine, D.S., 2012. Neural substrates of childhood anxiety disorders: a review of neuroimaging findings. *Child Adolesc. Psychiatr. Clin. N. Am.* 21 (3), 501–525. <https://doi.org/10.1016/j.chc.2012.05.002>.
- Blair, R.J.R., 2003. Facial expressions, their communicatory functions and neuro-cognitive substrates. *Philos. Trans. Biol. Sci.* 358 (1431), 561–572. <https://doi.org/10.1098/rstb.2002.1220>.
- Blair, R.J.R., 2013. The neurobiology of psychopathic traits in youths. *Nat. Rev. Neurosci.* 14 (11), 786–799. <https://doi.org/10.1038/nrn3577>.
- Blair, R.J.R., Morris, J.S., Frith, C.D., Perrett, D.I., Dolan, R.J., 1999. Dissociable neural responses to facial expressions of sadness and anger. *Brain* 122 (Pt 5), 883–893.
- Bliss, C.I., Greenwood, M.L., White, E.S., 1956. A rankit analysis of paired comparisons for measuring the effect of sprays on flavor. *Biometrics* 12 (4), 381–403. <https://doi.org/10.2307/3001679>.
- Bradley, R.H., Corwyn, R.F., 2002. Socioeconomic status and child development. *Annu. Rev. Psychol.* 53, 371–399. <https://doi.org/10.1146/annurev.psych.53.100901.135233>.
- Bradley, R.H., Corwyn, R.F., McAdoo, H.P., Coll, C.G., 2001. The home environments of children in the United States part I: variations by age, ethnicity, and poverty status. *Child Dev.* 72 (6), 1844–1867.
- Chen, E., Matthews, K.A., 2003. Development of the cognitive appraisal and understanding of social events (CAUSE) videos. *Health Psychology* 22 (1), 106–110.
- Chorpita, B.F., Yim, L., Moffitt, C., Umemoto, L.A., Francis, S.E., 2000. Assessment of symptoms of DSM-IV anxiety and depression in children: a revised child anxiety and depression scale. *Behav. Res. Ther.* 38 (8), 835–855.
- Cohen, S., Alper, C.M., Doyle, W.J., Adler, N.E., Treanor, J.J., Turner, R.B., 2008. Objective and subjective socioeconomic status and susceptibility to the common cold. *Health Psychology* 27 (2), 268–274. <https://doi.org/10.1037/0278-6133.27.2.268>.
- Cox, R.W., 1996. AFNI: software for analysis and visualization of functional magnetic resonance neuroimages. *Comput. Biomed. Res.* 29 (3), 162–173. <https://doi.org/S0010480996900142> [pii].
- Cox, R.W., Chen, G., Glen, D.R., Reynolds, R.C., Taylor, P.A., 2017. FMRI clustering in AFNI: false-positive rates redux. *Brain Connect.* 7 (3), 152–171. <https://doi.org/10.1089/brain.2016.0475>.
- Dückers, M.L.A., Alisic, E., Brewin, C.R., 2016. A vulnerability paradox in the cross-national prevalence of post-traumatic stress disorder. *British J. Psychiatry* 209 (4), 300–305. <https://doi.org/10.1192/bjp.bp.115.176628>.
- Eklund, A., Nichols, T.E., Knutsson, H., 2016. Cluster failure: why fMRI inferences for spatial extent have inflated false-positive rates. *Proc. Natl. Acad. Sci. U.S.A.* 113 (28), 7900–7905. <https://doi.org/10.1073/pnas.1602413113>.
- Ekman, P., Friesen, W.V., 1976. *Pictures of Facial Affect*. Consulting Psychologists Press, Palo Alto.
- Evans, G.W., 2004. The environment of childhood poverty. *Am. Psychol.* 59 (2), 77–92.

- <https://doi.org/10.1037/0003-066X.59.2.77>.
- Evans, G.W., English, K., 2002. The environment of poverty: multiple stressor exposure, psychophysiological stress, and socioemotional adjustment. *Child Dev.* 73 (4), 1238–1248.
- George, D., Mallery, P., 2016. *SPSS for Windows Step by Step: A Simple Guide and Reference*, 14th ed. Routledge, Abingdon-on-Thames, UK.
- Gianaros, P.J., Horenstein, J.A., Hariri, A.R., Sheu, L.K., Manuck, S.B., Matthews, K.A., Cohen, S., 2008. Potential neural embedding of parental social standing. *Soc. Cogn. Affect. Neurosci.* 3 (2), 91–96. <https://doi.org/10.1093/scan/nsn003>.
- Goodman, E., Adler, N.E., Kawachi, I., Frazier, A.L., Huang, B., Colditz, G.A., 2001. Adolescents' perceptions of social status: development and evaluation of a new indicator. *Pediatrics* 108 (2), E31.
- Hackman, D.A., Gallop, R., Evans, G.W., Farah, M.J., 2015. Socioeconomic status and executive function: developmental trajectories and mediation. *Dev. Sci.* 18 (5), 686–702. <https://doi.org/10.1111/desc.12246>.
- Hein, T.C., Monk, C.S., 2016. Research Review: neural response to threat in children, adolescents, and adults after child maltreatment - a quantitative meta-analysis. *J. Child Psychol. Psychiatry*. <https://doi.org/10.1111/jcpp.12651>.
- Hooker, C.I., Germine, L.T., Knight, R.T., D'Esposito, M., 2006. Amygdala response to facial expressions reflects emotional learning. *J. Neurosci.* 26 (35), 8915–8922. <https://doi.org/10.1523/jneurosci.3048-05.2006>.
- Hwa-Froelich, D.A., Matsuo, H., Becker, J.C., 2014. Emotion identification from facial expressions in children adopted internationally. *Am. J. Speech. Pathol.* 23 (4), 641–654. https://doi.org/10.1044/2014_AJSLP-14-0009.
- Javanbakht, A., King, A.P., Evans, G.W., Swain, J.E., Angstadt, M., Phan, K.L., Liberzon, I., 2015. Childhood poverty predicts adult amygdala and frontal activity and connectivity in response to emotional faces. *Front. Behav. Neurosci.* 9, 154. <https://doi.org/10.3389/fnbeh.2015.00154>.
- Kerestes, R., Davey, C.G., Stephanou, K., Whittle, S., Harrison, B.J., 2013. Functional brain imaging studies of youth depression: a systematic review. *Neuroimage Clin.* 4, 209–231. <https://doi.org/10.1016/j.nicl.2013.11.009>.
- Luby, J., Belden, A., Botteron, K., Marrus, N., Harms, M.P., Babb, C., et al., 2013. The effects of poverty on childhood brain development: the mediating effect of caregiving and stressful life events. *JAMA Pediatr.* 167 (12), 1135–1142. <https://doi.org/10.1001/jamapediatrics.2013.3139>.
- Marsh, A.A., Finger, E.C., Mitchell, D.G., Reid, M.E., Sims, C., Kosson, D.S., et al., 2008. Reduced amygdala response to fearful expressions in children and adolescents with callous-unemotional traits and disruptive behavior disorders. *Am. J. Psychiatry* 165 (6), 712–720. <https://doi.org/10.1176/appi.ajp.2007.07071145>.
- Martin, A., 2007. The representation of object concepts in the brain. *Annu. Rev. Psychol.* 58 (1), 25–45. <https://doi.org/10.1146/annurev.psych.57.102904.190143>.
- McCrorry, E.J., De Brito, S.A., Sebastian, C.L., Mechelli, A., Bird, G., Kelly, P.A., Viding, E., 2011. Heightened neural reactivity to threat in child victims of family violence. *Curr. Biol.* 21 (23), R947–8. <https://doi.org/10.1016/j.cub.2011.10.015>.
- McCrorry, E.J., Gerin, M.I., Viding, E., 2017. Annual Research Review: childhood maltreatment, latent vulnerability and the shift to preventative psychiatry – the contribution of functional brain imaging. *J. Child Psychol. Psychiatry* 58 (4), 338–357. <https://doi.org/10.1111/jcpp.12713>.
- McLaughlin, K.A., Sheridan, M.A., 2016. Beyond cumulative risk: a dimensional approach to childhood adversity. *Curr. Dir. Psychol. Sci.* 25 (4), 239–245. <https://doi.org/10.1177/0963721416655883>.
- McLaughlin, K.A., Costello, E.J., Leblanc, W., Sampson, N.A., Kessler, R.C., 2012. Socioeconomic status and adolescent mental disorders. *Am. J. Public Health* 102 (9), 1742–1750. <https://doi.org/10.2105/AJPH.2011.300477>.
- McLaughlin, K.A., Sheridan, M.A., Lambert, H.K., 2014. Childhood adversity and neural development: deprivation and threat as distinct dimensions of early experience. *Neurosci. Biobehav. Rev.* 47, 578–591. <https://doi.org/10.1016/j.neubiorev.2014.10.012>.
- McLaughlin, K.A., Peverill, M., Gold, A.L., Alves, S., Sheridan, M.A., 2015. Child maltreatment and neural systems underlying emotion regulation. *J. Am. Acad. Child Adolesc. Psychiatry* 54 (9), 753–762. <https://doi.org/10.1016/j.jaac.2015.06.010>.
- Meffert, H., Brislin, S.J., White, S.F., Blair, J.R., 2015. Prediction errors to emotional expressions: the roles of the amygdala in social referencing. *Soc. Cogn. Affect. Neurosci.* 10 (4), 537–544. <https://doi.org/10.1093/scan/nsu085>.
- Miller, G.E., Chen, E., Parker, K.J., 2011. Psychological stress in childhood and susceptibility to the chronic diseases of aging: moving toward a model of behavioral and biological mechanisms. *Psychol. Bull.* 137 (6), 959–997. <https://doi.org/10.1037/a0024768>.
- Mogg, K., Bradley, B.P., 1998. A cognitive-motivational analysis of anxiety. *Behav. Res. Ther.* 36 (9), 809–848.
- Noble, K.G., Houston, S.M., Kan, E., Sowell, E.R., 2012. Neural correlates of socioeconomic status in the developing human brain. *Dev. Sci.* 15 (4), 516–527. <https://doi.org/10.1111/j.1467-7687.2012.01147.x>.
- Noble, K.G., Houston, S.M., Brito, N.H., Bartsch, H., Kan, E., Kuperman, J.M., et al., 2015. Family income, parental education and brain structure in children and adolescents. *Nat. Neurosci.* 18 (5), 773–778. <https://doi.org/10.1038/nn.3983>.
- Oatley, K., Johnson-Laird, P.N., 1987. Towards a cognitive theory of emotions. *Cogn. Emot.* 1 (1), 29–50. <https://doi.org/10.1080/02699938708408362>.
- Operario, D., Adler, N.E., Williams, D.R., 2004. Subjective social status: reliability and predictive utility for global health. *Psychol. Health* 19 (2), 237–246.
- Parker, S.W., Nelson, C.A., Bucharest Early Intervention Project Core Group, 2005. An event-related potential study of the impact of institutional rearing on face recognition. *Dev. Psychopathol.* 17 (3), 621–639. <https://doi.org/10.1017/S0954579405050303>.
- Pessoa, L., Adolphs, R., 2010. Emotion processing and the amygdala: from a “low road” to “many roads” of evaluating biological significance. *Nat. Rev. Neurosci.* 11 (11), 773–783. <https://doi.org/10.1038/nrn2920>.
- 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. <https://doi.org/10.1016/j.neuron.2005.09.025>.
- Pollak, S.D., Sinha, P., 2002. Effects of early experience on children's recognition of facial displays of emotion. *Dev. Psychol.* 38 (5), 784–791.
- Pollak, S.D., Tolley-Schell, S.A., 2003. Selective attention to facial emotion in physically abused children. *J. Abnorm. Psychol.* 112 (3), 323–338.
- Pollak, S.D., Cicchetti, D., Hornung, K., Reed, A., 2000. Recognizing emotion in faces: developmental effects of child abuse and neglect. *Dev. Psychol.* 36 (5), 679–688. <https://doi.org/10.1037/0012-1649.36.5.679>.
- Pollak, S.D., Messner, M., Kistler, D.J., Cohn, J.F., 2009. Development of perceptual expertise in emotion recognition. *Cognition* 110 (2), 242–247. <https://doi.org/10.1016/j.cognition.2008.10.010>.
- Romeo, R.R., Leonard, J.A., Robinson, S.T., West, M.R., Mackey, A.P., Rowe, M.L., Gabrieli, J.D.E., 2018. Beyond the 30-Million-Word gap: children's conversational exposure is associated with language-related brain function. *Psychol. Sci.* 29 (5), 700–710. <https://doi.org/10.1177/0956797617742725>.
- Rosen, M.L., Sheridan, M.A., Sambrook, K.A., Dennison, M.J., Jenness, J.L., Askren, M.K., et al., 2018a. Salience network response to changes in emotional expressions of others is heightened during early adolescence: relevance for social functioning. *Dev. Sci.* 21 (3), e12571. <https://doi.org/10.1111/desc.12571>.
- Rosen, M.L., Sheridan, M.A., Sambrook, K.A., Meltzoff, A.N., McLaughlin, K.A., 2018b. Socioeconomic disparities in academic achievement: a multi-modal investigation of neural mechanisms in children and adolescents. *NeuroImage* 173, 298–310. <https://doi.org/10.1016/j.neuroimage.2018.02.043>.
- Rosen, M.L., Sheridan, M.A., Sambrook, K.A., Peverill, M.R., Meltzoff, A.N., McLaughlin, K.A., 2018c. The role of visual association cortex in associative memory formation across development. *J. Cogn. Neurosci.* 30 (3), 365–380. https://doi.org/10.1162/jocn_a_01202.
- Sampson, R.J., Raudenbush, S.W., Earls, F., 1997. Neighborhoods and violent crime: a multilevel study of collective efficacy. *Science* 277 (5328), 918–924.
- Selner-O'Hagan, M.B., Kindlon, D.J., Buka, S.L., Raudenbush, S.W., Earls, F.J., 1998. Assessing exposure to violence in urban youth. *J. Child Psychol. Psychiatry* 39 (2), 215–224.
- Shackman, J.E., Pollak, S.D., 2014. Impact of physical maltreatment on the regulation of negative affect and aggression. *Dev. Psychopathol.* 26 (4 Pt 1), 1021–1033. <https://doi.org/10.1017/S0954579414000546>.
- Shackman, J.E., Shackman, A.J., Pollak, S.D., 2007. Physical abuse amplifies attention to threat and increases anxiety in children. *Emotion* 7 (4), 838–852. <https://doi.org/10.1037/1528-3542.7.4.838>.
- Sheridan, M.A., McLaughlin, K.A., 2014. Dimensions of early experience and neural development: Deprivation and threat. *Trends in Cognitive Sciences* 18 (11), 580–585. <https://doi.org/10.1016/j.tics.2014.09.001>.
- Suzuki, H., Luby, J.L., Botteron, K.N., Dietrich, R., McAvoy, M.P., Barch, D.M., 2014. Early life stress and trauma and enhanced limbic activation to emotionally valenced faces in depressed and healthy children. *J. Am. Acad. Child Adolesc. Psychiatry* 53 (7), 800–813. <https://doi.org/10.1016/j.jaac.2014.04.013>. e10.
- Talairach, J., Tournoux, P., 1988. *Co-Planar Stereotaxic Atlas of the Human Brain: 3-D Proportional System: An Approach to Cerebral Imaging*, 1st ed. Thieme, Stuttgart.
- Thomson, C.C., Roberts, K., Curran, A., Ryan, L., Wright, R.J., 2002. Caretaker-child concordance for child's exposure to violence in a preadolescent inner-city population. *Arch. Pediatr. Adolesc. Med.* 156 (8), 818–823.
- Current Population Survey: Definitions and Explanations. U.S. Census Bureau, Washington, DC Retrieved from. <http://www.census.gov/population/www/cps/cpsdef.html>.
- Weisleder, A., Fernald, A., 2013. Talking to children matters: early language experience strengthens processing and builds vocabulary. *Psychol. Sci.* 24 (11), 2143–2152. <https://doi.org/10.1177/0956797613488145>.