Effects of childhood poverty and chronic stress on emotion regulatory brain function in adulthood

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Childhood poverty has pervasive negative physical and psychological health sequelae in adulthood. Exposure to chronic stressors may be one underlying mechanism for childhood poverty–health relations by influencing emotion regulatory systems. Animal work and human cross-sectional studies both suggest that chronic stressor exposure is associated with amygdala and prefrontal cortex regions important for emotion regulation. In this longitudinal functional magnetic resonance imaging study of 49 participants, we examined associations between childhood poverty at age 9 and adult neural circuitry activation during emotion regulation at age 24. To test developmental timing, concurrent, adult income was included as a covariate. Adults with lower family income at age 9 exhibited reduced ventrolateral and dorsolateral prefrontal cortex activity and failure to suppress amygdala activation during effortful regulation of negative emotion at age 24. In contrast to childhood income, concurrent adult income was not associated with neural activity during emotion regulation. Furthermore, chronic stressor exposure across childhood (at age 9, 13, and 17) mediated the relations between family income at age 9 and ventrolateral and dorsolateral prefrontal cortex activity at age 24. The findings demonstrate the significance of childhood chronic stress exposures in predicting neural outcomes during emotion regulation in adults who grew up in poverty.

fMRI | childhood adversity | socioeconomic status | reappraisal

Childhood poverty is related to increased risk of psychopathology (1–3) and physical illness in adulthood (4, 5). Furthermore, childhood poverty predicts adult morbidity irrespective of adult poverty (5–7). One possible mechanism to explain the far-reaching effects of childhood poverty on health is chronic stress (8). Chronic exposure to stressors associated with living in low-income families has long-term negative effects on physiological stress regulatory systems (9–12), eventually resulting in pathology (13, 14). Growing evidence suggests exposure to chronic stress and socioeconomic adversity produces lasting neurobiological changes (15, 16). However, little is known about whether childhood poverty is prospectively associated with central nervous system mechanisms involved in emotion regulation. Such knowledge may provide insights into identifying neural patterns for emotion regulatory dysfunction among adults who grew up in childhood poverty. The amygdala and prefrontal cortex (PFC) play a critical role for stress and emotion regulation. The amygdala detects and responds to threats from the environment, activating physiological stress responses (17). The PFC is widely considered as a top-down region that regulates the amygdala (18, 19). More specifically, the ventrolateral PFC (VLPFC), dorsolateral PFC (DLPFC), and medial PFC (mPFC) implement cognitive strategies such as cognitive reappraisal involved in emotion regulation (18–20). During reappraisal of negative stimuli, increased activity in the VLPFC, DLPFC, and mPFC regions is associated with diminished amygdala reactivity to negative stimuli as well as decreased perceived negative affect (21). Amygdala and PFC dysregulation has also been observed in populations with mood dysregulation, including depression (22), anxiety disorders (23, 24) including post-traumatic stress disorder (25), impulsive aggression (26), and substance abuse (27). Aberrant amygdala reactivity and inefficient or blunted PFC regulatory function are considered a neurobiological mechanism involved in impaired emotion regulation in these psychiatric disorders. Amygdala and PFC functions have also been shown to be affected by socioeconomic disparities (28, 29). In children, low socioeconomic status (SES) has been related to greater amygdala volume (30) and reduced PFC activity during cognitive tasks (31). In adults, retrospective reports of childhood SES were associated with elevated amygdala activity while processing negative facial expressions independently of adult SES (32) and reduced VLPFC activity while experiencing social exclusion (33). However, whether the amygdala and PFC functions associated with childhood poverty are directly related to effortful emotion regulation has never been examined. At present, little is known about underlying mechanisms that account for the relation between childhood SES and neural functioning. Chronic stress is one hypothetical mediator of the negative link between childhood poverty and adult health outcomes (8, 10). For example, children living in poverty are more likely to be exposed to multiple chronic stressors including violence, family turmoil, separation from family members, and substandard living environments (34, 35). In our previous studies, poverty exposure at age 9 prospectively predicted physiological stress dysregulation (34) and emotion dysregulation.

Significance

Childhood poverty has been linked to emotion dysregulation, which is further associated with negative physical and psychological health in adulthood. The current study provides evidence of prospective associations between childhood poverty and adult neural activity during effortful attempts to regulate negative emotion. Adults with lower family income at age 9 exhibited reduced ventrolateral and dorsolateral prefrontal cortex activity and failure to suppress amygdala activity at age 24. Chronic stressor exposure across childhood mediated the relations between family income at age 9 and prefrontal cortex activity. The concurrent adult income, on the other hand, was not associated with neural activity. The information on the developmental timing of poverty effects and neural mechanisms may inform early interventions aimed at reducing health disparities.


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(36, 37) in adolescence when concurrent levels of poverty exposure were controlled. In these studies, poverty exposure at age 9 was concurrently and prospectively associated with chronic stress exposure at age 9, 13, and 17 (37–39), and elevated chronic stress, in turn, mediated the association between childhood poverty and later outcomes. Furthermore, animal studies and recent human brain imaging studies demonstrate that repeated exposure to chronic stress impacts amygdala and PFC development, potentially leading to impaired emotion regulation (40–43).

Therefore, in this longitudinal study, we investigated whether childhood family income was associated prospectively with adult neural activity in the amygdala and PFC during emotion regulation. We also examined a stress pathway linking childhood poverty and the subsequent neural functions for emotion regulation. The current study used family income assessed at age 9 as a direct measure of childhood poverty exposure. To investigate the developmental timing of poverty and neural functioning, we examined the link between childhood poverty and adult neural functioning after controlling for adult income levels. We used a well-established emotion regulation functional magnetic resonance imaging (fMRI) paradigm (18, 44), in which participants are instructed to experience the natural emotional state (Maintain) or to decrease the intensity of their negative affect by using cognitive reappraisal (Reappraisal) while viewing negative images. We hypothesized that, in the contrast of Reappraisal vs. Maintain conditions, low family income at age 9 would be associated with increased amygdala and decreased PFC activation. The amygdala and PFC activation may also be associated with self-reports of emotion regulation (Materials and Methods). Furthermore, we assessed chronic stress by averaging exposure to multiple physical (i.e., substandard housing, crowding, and noise) and social (i.e., family turmoil, violence, and child–family separation) risk factors across ages 9–17. We hypothesized that the influence of childhood income on amygdala and PFC activity would be mediated by chronic stress exposure throughout childhood.

**Results**

**Descriptive and Behavioral Data.** Ratings of negative affective state between two conditions, Reappraisal and Maintain, were significantly different, t(48) = 4.13, P < 0.001. The average ratings decreased from the Maintain (mean = 2.93 ± 0.81) to Reappraisal (mean = 2.48 ± 0.95). However, the success of regulating negative emotions (calculated by subtracting Reappraisal ratings from Maintain ratings) was not significantly associated with family income at age 9, chronic stress exposure across ages 9–17, or current adult income levels at age 24.

**Family Income at Age 9 and Neural Emotion Regulation at Age 24.** Reappraisal of emotion (compared with maintaining one’s emotional response) produced greater activation in bilateral inferior/middle/superior frontal gyrus, precentral gyrus, striatum, insula, parietal lobe, and temporal gyrus (P < 0.05, corrected for multiple comparisons; Materials and Methods). However, no amygdala activation was detected in the contrast of Reappraisal vs. Maintain using a region of interest (ROI) approach, although bilateral amygdala activation was detected on Reappraisal (vs. Baseline) and Maintain (vs. Baseline) conditions (P < 0.05, corrected).

Enhanced neural activation during Reappraisal was predicted by family income at age 9. In particular, in the contrast of the Reappraisal vs. Maintain, lower family income at age 9 predicted reduced activation in the left DLPFC (Fig. 1A), VLPFC/insula/temporopolar area (Fig. 1B), precentral gyrus, and inferior parietal lobe/superior temporal gyrus (P < 0.05, corrected; Table 1; all analyses controlled for current income). No cluster was identified with a significant positive association with the current, adult income level.

Amygdala ROI analysis revealed that activation in the Reappraisal vs. Maintain conditions was negatively associated with childhood income in the left amygdala [r(46) = 2.48, x, y, z = –30, –4, –22; 140 voxels] (P < 0.05, uncorrected) (Fig. 1C), controlling for adult income level. Besides the amygdala activity from ROI analysis, no other cluster showed a negative association with family income at age 9 or current adult income level.

Furthermore, we explored functional connectivity between the left amygdala and VLPFC/DLPFC regions using the psychophysiological interaction (PPI) analysis at P < 0.001, uncorrected, cluster size > 10 voxels (SI Text). The analysis revealed that amygdala activity was positively coupled with the left VLPFC [x, y, z = –58, 18, 8; 58 voxels; r(46) = 3.97; Fig. S1] during Reappraisal among individuals with lower family income at age 9, whereas amygdala activity was negatively coupled with the left VLPFC during Reappraisal among individuals with higher family income at age 9 (Fig. S2). Family income at age 9 was not associated with the amygdala–DLPFC connectivity.

Finally, we calculated the correlation between regulation success scores and the amygdala, VLPFC, and DLPFC activity during Reappraisal. The correlation analysis revealed that Reappraisal success was positively correlated with both DLPFC [r (49) = 0.31, P < 0.05] and VLPFC [r(49) = 0.27, P < 0.05], but not with amygdala activity. Thus, DLPFC and VLPFC activity during Reappraisal was associated with greater success in down-regulating negative emotions. However, the use of everyday reappraisal coping (Materials and Methods) was not associated with the neural activity.

**Fig. 1.** The upper panels are regions showing a significant association with family income-to-needs ratio at age 9. (A) Dorsolateral prefrontal cortex (PFC) [x, y, z = –40, 12, 28; 343 voxels; P < 0.05, corrected]. (B) Ventrolateral PFC, insula, temporopolar area [x, y, z = –46, 10; –8; 672 voxels; P < 0.05, corrected]. (C) Amygdala [x, y, z = –30, –4, –22; 140 voxels; P < 0.05, uncorrected]. The lower panels depict partial regression plots describing the associations between family income-to-needs ratio at age 9 and parameter estimates of a region in the contrast of Reappraisal vs. Maintain, controlling for adult income level.
Childhood Chronic Stressor Exposure as a Mediator. We next tested whether exposure to chronic stressors during childhood (ages 9–17) mediated the relations between family income at age 9 and adult DLPFC and VLPFC activity during Reappraisal. Elevated childhood chronic stress exposure mediated the associations between family income at age 9 and increased adult left DLPFC activity during Reappraisal, controlling for concurrent, adult income (Fig. 2A). The addition of childhood chronic stress shrunk the beta weight for childhood income 75%, which was no longer significant and suggested full mediation [indirect effect = 0.09, 95% confidence intervals (CIs) = 0.02–0.18].

Because the size of the suprathreshold cluster including the left VLPFC was large and contained other parietal and temporal regions, an ROI approach was used to separate the estimated activity of the left VLPFC from the estimated activity of other regions. We placed an 8 mm radius sphere at the left VLPFC peak (x, y, z = −50, 22, 6) from a meta-analysis of fMRI reappraisal studies (19). We found elevated chronic stress exposure across ages 9–17 mediated the relations between family income at age 9 and increased left VLPFC activity during Reappraisal, controlling for concurrent adult income (Fig. 2B). The addition of childhood chronic stress shrunk the beta weight for childhood income 64%, which was no longer significant and suggested full mediation (indirect effect = 0.09, 95% CIs = 0.02–0.16). An analysis performed on amygdala activity did not find a mediation effect.

Discussion

We examined whether childhood poverty was prospectively linked to adult neural activity in the PFC and amygdala, regions centrally involved in emotional regulation. We found a significant relation between childhood income and neural functions. During emotion regulation with cognitive reappraisal, lower family income at age 9 was associated with reduced activity in the adult DLPFC and VLPFC but increased amygdala activity. In contrast to childhood income level, current income level as an adult was not linked to neural activity during emotion regulation. When the individual’s stress history was incorporated into our model, exposure to chronic stressors throughout childhood (i.e., ages 9–17) mediated the links between family income at age 9 and reduced adult DLPFC and VLPFC activity. Reduced PFC and increased amygdala activity among adults who grew up in poverty provides evidence for neural embedding of childhood poverty. Furthermore, the mediating role of chronic stressor exposure in childhood may help account for the link between childhood poverty and adult neural functions, which may contribute to physiological and psychological stress regulation difficulties.

We found that lower family income at age 9 was associated with reduced DLPFC and VLPFC activity in 24-y-olds during emotion regulation using cognitive reappraisal. Both DLPFC and VLPFC are involved in cognitive control and executive functioning and facilitate goal-directed behaviors (45). Furthermore, increased DLPFC and VLPFC activity was associated with greater success in down-regulating negative emotions, further supporting the role of these cortical regions in emotion regulation. In contrast to reduced DLPFC and VLPFC activity, family income at age 9 was associated with increased adult amygdala activity during emotion regulation. More specifically, the data in Fig. 1C suggest that in adults who had higher family income at age 9, the negative values of neural activity suggest less amygdala activity during Reappraisal relative to the Maintain condition. However, in those with lower family income at age 9, the positive values of neural activity suggest greater amygdala activity during Reappraisal than Maintain, indicating potential failure of amygdala regulation using Reappraisal. The functional connectivity findings further suggested altered relations between the amygdala and VLPFC activity in the context of childhood poverty exposure. A negative amygdala–VLPFC coupling among individuals with lower family income at age 9 suggests that higher childhood family income is associated with greater VLPFC activity to suppress amygdala activity during emotion regulation. On the other hand, a positive amygdala–VLPFC coupling during Reappraisal suggests that lower childhood income is associated with ineffective amygdala activity suppression of the VLPFC activity during emotion regulation. Such failure of amygdala regulation, in part by the dampened VLPFC and DLPFC activity, has been suggested as neural deficits in many psychiatric illnesses associated with childhood exposure to chronic stress.

With regard to the amygdala findings, we found no main effect of Reappraisal (vs. Maintain) on diminishing amygdala activity; therefore, the potential interpretation of the reappraisal-related

Table 1. Brain areas with the positive associations between family income-to-needs ratio at age 9 and neural activity in the Reappraise vs. Maintain contrast at age 24

<table>
<thead>
<tr>
<th>Area of activation</th>
<th>Brodmann area</th>
<th>Side</th>
<th># voxels</th>
<th>MNI coordinates</th>
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<tbody>
<tr>
<td>Dorsolateral PFC</td>
<td>9, 46</td>
<td>L</td>
<td>343</td>
<td>−40 12 28</td>
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<td></td>
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<td></td>
<td></td>
<td>3.99</td>
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<td>−46 0 48</td>
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<td>3.92</td>
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<td>−42 2 38</td>
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<tr>
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<td></td>
<td>3.13</td>
</tr>
<tr>
<td>Ventrolateral PFC</td>
<td>47, 13, 38</td>
<td>L</td>
<td>672</td>
<td>−46 10 −8</td>
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<tr>
<td>Insula</td>
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<td></td>
<td>4.04</td>
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<tr>
<td>Temporopolar area</td>
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<td>−28 14 −14</td>
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<tr>
<td>Precentral gyrus</td>
<td>6, 8</td>
<td>R, L</td>
<td>602</td>
<td>−48 22 −2</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.30</td>
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<tr>
<td>Superior temporal</td>
<td>22, 40</td>
<td>L</td>
<td>293</td>
<td>−56 −56 30</td>
</tr>
</tbody>
</table>

P < 0.05, corrected. L, left; MNI, Montreal Neurological Institute; PFC, prefrontal frontal cortex; R, right.

Fig. 2. A path diagram showing a mediation model with the unstandardized coefficients for each association. Chronic stress exposure across ages 9–17 mediated the relationship between family income-to-needs ratio and neural activity during Reappraisal in (A) dorsolateral prefrontal cortex (DLPFC) and (B) ventrolateral prefrontal cortex (VLPFC). ***P < 0.001, *P < 0.05.
amygdala modulation is limited to the context of variability in childhood family income at age 9. Reduction in amygdala activation during Reappraisal has been inconsistently reported across previous studies (22, 44, 46). The reason for the inconsistent findings may be associated with different types of regulatory strategies used across different studies. All regulatory strategies require emotional appraisal and attention to emotional stimuli—processes strongly associated with amygdala activity (47). However, some strategies such as positive reinterpretation or distancing from the content of negative stimuli may recruit more amygdala activity than distraction (directing attention away from negative stimuli) (48). The current study focused on positive re-interpretation and distancing, and this may have produced no main effect on amygdala activity during Reappraisal vs. Maintain. In fact, temporal gyrus VLPFC and DLPFC functioning, childhood poverty predicted activity in several other frontal, parietal, and temporal regions of the adult brain, including the precentral gyrus, inferior parietal lobe, superior temporal gyrus, and temporo-polar gyrus, during cognitive reappraisal. In all of these regions, low family income at age 9 predicted reduced activity during cognitive reappraisal. Each of these regions has been shown to be involved in emotion regulation via cognitive reappraisal (18, 19, 44). The precentral gyrus contributes to the top-down control of cognitive and emotional processes through selective attention. Although we did not find a significant association between childhood income and mPFC, involvement in reappraisal, the precentral gyrus is structurally interconnected and frequently activated with the mPFC as well as lateral PFC during Reappraisal (50). The inferior parietal lobe is a part of the attention system along with the DLPFC (51). Thus, the activity in the precentral gyrus and inferior parietal lobe may contribute to reappraisal by selectively monitoring information. Previously, adult retrospective reports of childhood SES have been associated with lower activity in the inferior parietal lobe during monetary reward processing (52). Temporopolar area and superior temporal gyrus responses are related to the representation of perceptual and semantic information that likely assist in the reappraisal process (18). Thus, the significant associations between childhood family income and neural activity in these regions uncovered herein may reflect the pervasive effects of childhood SES disparities on neural functions across multiple regions involved in emotional regulation.

We also tested the hypothesis that exposure to chronic stressors across ages 9–17 would help explain the relations between childhood poverty and reduced DLPFC and VLPFC activity during emotional reappraisal (49). Chronic stressors may be sensitive to childhood SES because childhood chronic stress exposure may mediate the relations between childhood poverty and functional brain activity (50). Childhood poverty is related to reduced DLPFC and VLPFC activity during emotion regulation among young adults. Furthermore, teaching coping skills including cognitive reappraisal helped adult, low-income women decrease their reliance on involuntary coping strategies and reduce their depressive symptoms (58). Thus, future studies should investigate whether childhood SES effects on the neural functioning during cognitive reappraisal are linked to everyday reappraisal efforts for particular stressors including financial hardships. The current study revealed that childhood poverty is related to reduced activity in the VLPFC and DLPFC and increased activity in the amygdala during emotion regulation among young adults. Furthermore, in both the DLPFC and VLPFC, childhood chronic stress exposure mediated the relations between childhood poverty and decreased activity during emotion regulation. The current study demonstrates the significance of childhood family income and stress exposure in predicting neural outcomes in young adults during emotion regulation. Greater knowledge about the developmental timing of risk exposures and brain development would be extremely valuable for informing interventions. Thus, future longitudinal studies should examine the timing of childhood poverty, stressor exposures, and brain development, ideally from conception throughout childhood.

Materials and Methods

Participants. Participants were initially recruited for a longitudinal study on rural poverty and child development (mean age, 9.2 y) in rural counties in the Northeastern United States from public schools, the Cooperative Extension
System, Head Start, and other antipoverty programs. One child per family participated, and low-income families were oversampled. The participants were followed up during wave 2 (mean age, 13.44 years; age range, 12–17 years). See Evans et al. (34, 35) for further details on subject recruitment and protocols.

Among individuals participating in these three waves of data collection, 54 participants were recruited for this study. This study was approved by the University of Michigan and Cornell University Institutional Review Boards, and all participants provided informed consent. All participants had no MRI contraindications (e.g., metallic/ferrous materials in their body), no prior or current treatment for any psychiatric disorder (clinician-conducted psychiatric evaluation based on the Structured Clinical Interview for Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV)), and no current neurological condition. Approximately half of the participants were from low-income backgrounds at age 9, and half were from families with incomes two to four times above the poverty line. Of 54 participants, 49 participants completed the Emotion Regulation Task (ERT) task, and had a full set of usable fMRI data. Two participants did not complete the task, one participant had a severe artifact in fMRI data, and two participants had excessive movement in fMRI data beyond our criteria (2 mm/2° in any direction). The average age was 23.61 (SD = 1.30, range, 20–27), and 55.1% (27 out of 49) were males. The average income-to-need ratio at age 9 was 1.8 (SD = 1.1) and at age 24 was 3.2 (SD = 3.0).

Procedure. In the longitudinal study, a pair of trained researchers visited children’s homes at each wave of data collection, independently interviewing the participant and his/her mother. Only one child per household was eligible for the study. Demographic information, measures of mental health, and chronic stress exposure were assessed during the home visits. In the fMRI study, participants visited the University of Michigan’s neuroimaging center, where trained researchers administered training and fMRI sessions.

Measures. Income-to-needs. The ratio of family income-to-needs was computed by dividing total family income by the poverty threshold at each wave of data collection. This ratio is an annually adjusted, per capita index of income that the US Census Bureau calculates using a standardized formula. The income-to-needs ratio at age 24 was calculated based on the participants’ own income. Chronic stress. Children’s exposure to chronic stress was assessed at wave 1 (age 9), wave 2 (age 13), and wave 3 (age 17). Chronic stress was operationalized in two ways: (i) a list of the 10 most frequent stressors from the Adolescent Perceived Events Scale (60), answering dichotomous questions about whether the stressor occurred in the child’s home at each wave of data collection, independently interview- ing the participant and his/her mother. Only one child per household was eligible for the study. Demographic information, measures of mental health, and chronic stress exposure were assessed during the home visits. In the fMRI study, participants visited the University of Michigan’s neuroimaging center, where trained researchers administered training and fMRI sessions.

Statistical Package for the Social Sciences (SPSS, Inc.) for additional analyses.

Event-related fMRI paradigm. Neural activity of participants was recorded while they were engaged in the ERT (44). During the Look condition of the ERT, partic- ipants were asked to simply look at pictures with emotionally neutral valence. During the Maintain task, participants were instructed to attend to and experience naturally (without trying to change or alter) the emotional state elicited by the pictures. During the Reappraisal task, participants were instructed to voluntarily decrease the intensity of their negative affect by using one of two strategies: (“I don’t think of this in a different light, to make it seem more positive”), and the summary score of the four items was indicated as an indicator of everyday use of reappraisal strategies.

fMRI data acquisition and preprocessing. Scanning took place in a 3.0 Tesla Philips magnet scanner in the fMRI laboratory at Veterans Affairs Ann Arbor using a standard eight-channel SENSE head coil. Functional data were acquired (300 T2*-weighted echo-planar-imaging (EPI) volumes; TR = 2,000 ms; TE = 30 ms; flip angle = 90°; field of view = 220 mm; matrix size, 64 × 64; 42 axial slices; voxels = 3.44 × 3.44 × 2.80 mm). A high-resolution anatomical T1-weighted image with a 3D gradient-recalled echo sequence (also acquired). Functional imaging data were processed and analyzed using Statistical Parametric Mapping 8 (Wellcome Trust Center for Neuroimaging, University College, London; www.fil.ion.ucl.ac.uk/spm). Five images at the beginning of each fMRI run were discarded. Slice timing correction was performed using a middle slice as a reference (slice 21), and then images within each run were realigned to the first image and the first run to correct for head motion. Realigned functional images were spatially normalized to a functional tem- plate, resampled to 2 × 2 × 2 mm voxels, and then spatially smoothed using a Gaussian filter (full width at half maximum, 8 mm).

Statistical analysis. At the individual subject level, response amplitudes were estimated for each condition using the general linear model. A high-pass filter of 0.0078 Hz was used. Conditions that were modeled included look, maintain, and reappraise blocks as well as instruction and rating periods. The current study was primarily interested in emotion regulation; thus, for individual subjects, we contrasted images of the blood-oxygen-level-dependent (BOLD) signal changes associated with the reappraisal vs. maintain contrast, which estimated the neural functions involved in explicit regulation of neg- ative emotion. For the group-level analysis, contrast images for individual subjects were entered into a random-effects analysis. To identify regions that were specifically active on Reappraisal relative to the first performance of anticipation in the Reappraisal vs. Maintain condition. To identify regions that were associated with childhood family income, a multiple regression was performed with the income-to-needs ratio at age 9 as an independent vari- able and the current income-to-needs ratio as a covariate of no interest. An initial voxel-wise threshold of P < 0.005 and a minimum cluster size of 265 voxels for the Reappraisal vs. Maintain contrast gave a corrected P ≤ 0.05. This threshold was determined by Monte-Carlo simulations using the 3dClustSim program of the AFNI toolkit (3dClustSim–mask = both –prefix = fwhm3x10.31 10.82 10.02; http://afni.nimh.nih.gov/pub/dist/doc/program_help/3dClustSim.html). The amygdala was a region of a priori interest and has a small struc- ture; thus, an ROI approach was used. A threshold of P < 0.05, uncorrected, was applied, and estimates of signal change for each contrast averaged across the entire suprathreshold region were extracted for each participant using MarsBaR (Marseille boîte à rêve d’intérêt) (65) and were then entered into Statistical Package for the Social Sciences (SPSS, Inc.) for additional analyses.

In the additional analyses, we used neural activity during the Reappraisal task alone (vs. Fixation), rather than contrasting Reappraisal against Maint- ain. We sought to isolate the effects of Reappraisal as Maintain because the contrast confounds potential interactions between the two tasks, both of which involve appraisal and implicit and explicit control, whereas the fixation condition approximates noncognitive/nonemotional control (“I don’t think of this in a different light, to make it seem more positive”). The same approach was used in previous studies (44, 48, 66, 66). First, we estimated regulation success of negative emotions by subtracting Reappraisal ratings from Maintain ratings (21). Then, the regulation success as well as
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