Family socioeconomic status modulates the coping-related neural response of offspring

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Substantial research links economic adversity to poor coping in stressful or threatening environments. Neuroimaging studies suggest that activation of the right ventrolateral prefrontal cortex (rVLPFC) plays a key role in self-control, and it seems that individual differences in neurocognitive systems underlying self-control are determined in part by subjective childhood socioeconomic status (SES). The present study used near-infrared spectroscopy (NIRS) to investigate whether subjective childhood SES moderates rVLPFC activity during one form of threatening environment: social exclusion. Twenty-five undergraduates participated in a NIRS session in which they were socially included and then excluded during an online ball-tossing game. Lower subjective childhood SES was associated with higher levels of social distress and lower levels of rVLPFC activity during social exclusion. The present findings suggest that early family environments are reliably associated with deficits in offspring coping resources and processes, as well as with difficulties in regulating interpersonal circumstances.

Keywords: subjective childhood SES; rVLPFC activity; social distress; regulation process; social threat

INTRODUCTION

Many lines of research have revealed that a harsh early environment affects mental and physical functioning across the lifespan, and coping processes are implicated in these relationships (e.g. Repetti et al., 2002). Aspects of early life that have been consistently tied to poor coping include immersion in various aversive life circumstances, including lower childhood socioeconomic status (SES). Substantial research links economic adversity (lower SES) to negative mental and physical health outcomes (e.g. Adler et al., 1999; Williams and Collins, 1995; Chen et al., 2002). SES is defined by material wealth, occupation and participation in educational and social institutions (Oakes and Rossi, 2003). SES can thus be measured objectively using self-reports of family income and educational attainment (e.g. Lachman and Weaver, 1998). Childhood SES appears to be specifically related to problems in the enlistment or use of coping resources to overcome a difficulty (Adler et al., 1999; Taylor and Seeman, 1999; Repetti et al., 2002). Lower SES early family environments are reliably associated with deficits in offspring coping resources, including optimism and psychological control (Repetti et al., 2002). Thus, the existing literature provides a foundation for a pathway linking lower SES to compromised development of coping resources and processes, and to a corresponding increased risk of aversive stress-related mental and physical health outcomes (e.g. Taylor and Stanton, 2007). In addition, there is some evidence that ‘subjective childhood SES’ is more strongly related to psychological functioning and health-related factors than are more objective indicators. For example, a previous study found that while subjective and objective SES are significantly correlated, subjective SES is more consistently and strongly related to psychological functioning (e.g. control over one’s life and active forms of control) and health-related outcomes (e.g. physical health and resting heart rate), compared with objective SES (Adler et al., 2000). Another study found childhood and adolescent SES to be better predictors of health outcomes than adult SES (Kittleson et al., 2006). It appears that various psychological functioning and health outcomes are associated with internalized perceptions of early SES (i.e. subjective childhood SES) that are themselves influenced by objective factors.

Interestingly, neuroimaging studies suggest that human brain development occurs within a socioeconomic context, such that childhood SES influences aspects of neural development, including cognitive and emotional processing (Hackman et al., 2010). Some evidence points toward a specific relationship between childhood SES and the neural processing of emotion. Lower parental subjective social status is associated with an increased amygdala response to explicitly threatening faces (Gianaros et al., 2008), with the amygdala known to play a pivotal role in the appraisal of emotionality and sources of threat. In addition, lower subjective social status covaries with reduced gray matter volume in the perigenual area of the anterior cingulate cortex (Gianaros et al., 2007). This paralimbic brain region has been implicated in adaptive emotional, behavioral and physiological responding responses to environmental and psychosocial stressors (Devinsky et al., 1995; Bush et al., 2000; Vogt, 2005). More importantly, these studies imply that individual differences in neurocognitive systems are determined in part by subjective childhood SES, and these systems therefore emerge as candidate pathways by which subjective childhood SES might increase the risk of affective and behavioral outcomes. If this possibility is correct, subjective childhood SES may modulate not only brain activity that reflects emotional appraisals and experiences but also the activity which reflects psychosocial coping or regulation of aversive emotional states. The present study focused on neural responses that reflect such psychosocial coping or regulation processes, examining whether subjective childhood SES moderates such neural responding under threatening circumstances.

What brain domain is related to psychosocial coping or affect regulation? Earlier neuroimaging work has confirmed that activation of the prefrontal cortex is associated with emotional regulation (Lebrecht and Badre, 2008). Many FMRI studies have observed increases in activity in the ventrolateral, dorsolateral and dorsomedial prefrontal cortices.
when participants are instructed to deploy cognitive strategies that mitigate a negative emotional experience (Ochsner and Gross, 2005). In particular, the right ventrolateral prefrontal cortex (rVLPFC) is known to modulate the activity of the amygdala (e.g. Lieberman, 2007). Although the rVLPFC has multiple functions (e.g. in working memory and attention), rVLPFC activity plays a key role in the exertion of self-control via cortical-subcortical pathways (Wager et al., 2008; Cohen and Lieberman, 2010). In addition, previous studies have confirmed that various coping resources contribute to the extent of such rVLPFC activity during threatening circumstances. For example, psychological resources (e.g. self-esteem and optimism) are associated with greater rVLPFC activity and less amygdala activity during a threat regulation task (Taylor et al., 2008). On the other hand, people high in rejection sensitivity show less rVLPFC activation in response to social rejection (Kross et al., 2007), as well as heightened reactivity to rejection cues and subsequent personal and interpersonal difficulties, such as the breakup of a relationship (Downey and Feldman, 1996; Downey et al., 1998), in comparison to people low in rejection sensitivity. The rVLPFC activity associated with stress-related circumstances appears to reflect psychosocial coping. At the same time, given an association between subjective childhood SES and psychosocial resources (Taylor and Stanton, 2007), it is possible that rVLPFC activity during threatening circumstances is affected not only by psychological resources but also subjective childhood SES, which appears to constitute one possible basis of such resources. Taking these findings together, we hypothesized that subjective lower childhood SES would be associated with dampened rVLPFC activity, and consequently suboptimal regulation of the social distress that is felt under threatening circumstances.

The present study focused on social exclusion occurring during a ball-tossing game, as one means to evoke feelings of social distress (Williams et al., 2000). Previous studies indicate that the rVLPFC activity associated with social distress during this game occurs in the case of social exclusion (when individuals are directly prevented from participating in a game or social activity by other players) (Eisenberger et al., 2003). Similar to studies of emotion regulation, neuroimaging studies of social exclusion suggest that rVLPFC activity plays an extremely important role in reactions to social exclusion (Eisenberger et al., 2003; Eisenberger and Lieberman, 2004; Kross et al., 2007; Yanagisawa et al., 2011). Regions such as the anterior cingulate cortex are involved in detecting or evaluating potential social exclusion threats, while regions such as the rVLPFC are involved in regulating or inhibiting social distress responses (e.g. Eisenberger et al., 2003). Given these findings, there are at least two potential reasons why people with subjective lower childhood SES might suffer from greater levels of social distress. Such individuals (i) might have a lower threat-detection threshold, meaning that events are more likely to be perceived as threatening in terms of social exclusion, and/or (ii) cannot regulate their responses to the threat once it is detected (Yanagisawa et al., 2011). Based on a viewpoint of association between subjective lower childhood SES and psychosocial coping, the present study focused on rVLPFC activity, which reflects the regulation of social distress (ii).

We utilized near-infrared spectroscopy (NIRS) to measure rVLPFC activity during the ball-tossing game, given that this technology allows for continuous monitoring of cerebral blood oxygenation using a portable probe within an ecologically valid setting (Ruocco et al., 2010). A pair of fiber ends (light emitter and detector) was attached to the surface of the scalp to record prefrontal activation while the subjects performed the tasks in a non-invasive and minimally restrictive way that does not require fixing the body in a gantry, as do functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) scans. The time needed for this attachment is usually <30 s, with little demand on the participants. NIRS has been used simultaneously with fMRI or PET scans, which demonstrated the reliability of the NIRS technique in monitoring cortical activation within the context of functional studies (Kleinschmidt et al., 1996; Hock et al., 1997; Punwani et al., 1997). A recent review article by Quaresima et al. (in press) has described features, advantages and limitations of using NIRS for human brain mapping. In this review, the authors point out that the typical depth sensitivity of most NIRS systems is ~1.5 cm, with a spatial resolution of ~1 cm. One previous study in particular has found a correlation between oxy-Hb measured with NIRS and regional cerebral blood flow (rCBF) measured with PET, which was restricted to a semisphere volume of brain tissue with a limited penetration depth of 0.45 to 1.575 cm (Hock et al., 1997). Thus, the pair of fiber ends can be attached to the ventral area of the prefrontal cortex according to the international 10–20 system (Jasper, 1958), such that the two-channel NIRS system implemented in the present protocol provides temporally precise measurements of oxy-hemoglobin (oxy-Hb) within those brain circuits restricted to the VLPFC. In this context, we hypothesized that subjective lower childhood SES would be associated with decreased oxy-Hb in the rVLPFC during exclusion, relative to higher childhood SES. Furthermore, such attenuated rVLPFC activity should be associated with difficulties in regulating the social distress that is felt during exclusion.

**METHODS**

**Participants**

Twenty-five undergraduates (16 females; mean age = 19.04 ± 1.21 years) at Hiijyama University in Hiroshima, Japan, participated in the experiment in exchange for compensation in the form of 500 yen (~6 USD). Participants gave their written informed consent after receiving a detailed description of the study. The Ethics and Safety Committee of Hiroshima University approved the study protocol.

**Procedure and materials**

Following the approach of Griskevicius et al. (2011), we measured the extent to which people experienced resource scarcity during childhood as a measure of subjective childhood SES. We asked participants to indicate their agreement with three statements each rated on a 7-point scale, with anchors from 1 (strongly disagree) to 7 (strongly agree). The following items were used (α = 0.78): (i) ‘My family usually had enough money for things when I was growing up’, (ii) ‘I grew up in a relatively wealthy neighborhood’ and (iii) ‘I felt relatively wealthy compared to the other kids in my school.’

Participants were told that they would be playing a virtual ball-tossing game over the Internet with two other players. In reality, they played against a preset computer program (Williams et al., 2000; Eisenberger et al., 2003; Zadro et al., 2004). Participants were told that the study was examining the effects of mental visualization, and that they would be playing an Internet ball-toss game on the computer in order to practice these skills. They were told that skilled performance in the game was unimportant and that the game was merely a means for them to engage their mental visualization skills. Participants all saw a ball, two other players on the left and right sides of the screen, and an arm representing the participant on the lower center portion of the screen. The other players threw the ball to each other or to the participant, waiting 1.0–2.0 s (determined randomly) before making a throw, in order to heighten the sense that the participant was actually playing with other individuals. The participant could return the ball to one of the players by pressing one of two keys on a button box.

The game consisted of two conditions, each portioned into three blocks (with a duration of ~45 s per block, and with 30 s rest periods between each block). The first three blocks comprised the inclusion
condition, during which participants received six or seven throws per block. The next three blocks comprised the exclusion condition, during which participants received just one or two throws from task onset to 10s into the task. After this point, the other two players stopped throwing participants the ball for the remainder of the scan. Following each condition, participants completed a questionnaire that assessed social distress. Previous research has indicated that social exclusion impedes the attainment of fundamental human needs (belonging, self-esteem, control, meaningful existence: Williams et al., 2000; Zadro et al., 2004; Williams, 2009). We therefore measured need dissatisfaction in response to social exclusion as an index of social distress, using eight items taken from the full 20-item pool of the need satisfaction scale (Williams, 2009), with each item rated on a 5-point scale. This questionnaire assessed participants’ subjective feelings during each task condition [e.g. ‘I felt rejected’; Cronbach’s alphas were 0.64 (inclusion) and 0.69 (exclusion)].

NIRS recording and processing

NIRS measurements were performed throughout the ball-tossing game, and were conducted using a two-channel NIRS system (NIRO 200, Hamamatsu Photonics, Japan). The basic principles of this technique (Jobsis, 1977) and its use in functional studies (Villringer et al., 1997; Benaron et al., 2000) have been described in detail elsewhere.

Briefly, the NIRS apparatus measures changes in oxy-Hb, deoxy-hemoglobin (deoxy-Hb) and total hemoglobin (total-Hb) in the cortical regions of the brain using a reflectance mode with three different wavelengths (775, 810 and 850 nm) of near-infrared light, based on the modified Beer-Lambert law (Cope and Delpy, 1988). The distance between the emitter and the detector was set at 4 or 5 cm, depending on the specific light attenuation. Recordings were acquired at a sampling rate of 1 Hz. All hemoglobin concentration values were expressed in mmol/l. The time resolution of the NIRS measurements was every 1 s. Two probe holders were placed on the left and right side of the forehead using double-sided adhesive tape. These positions in the ventral area of the prefrontal cortex were localized between Fp1 and F7 (left) and between Fp2 and F8 (right) respectively, according to the international 10–20 system (Jasper, 1958). The participants sat on a chair with their eyes open throughout the measurements and were asked not to move their head, legs, or any other part of their bodies unrelated to the task, in order to reduce artifacts. Changes in oxy-Hb were measured during the game.

Since change in oxy-Hb is the most sensitive indicator of rCBF (Hoshi et al., 2001; Strangman et al., 2002), we evaluated changes in oxy-Hb signals. Average oxy-Hb levels were calculated for the pre-task baseline, for each participant. The last 15 s of the pre-task period was defined as the baseline. The average level difference between activation condition and baseline was defined as the size of activation (Δoxy-Hb). In the statistical analysis, we used z-scores for Δoxy-Hb levels during each condition.

We adopted hierarchical regression analysis according to previous recommendations (Aiken and West, 1991; Cohen et al., 2003). When continuous variable are studied, the use of ANOVA is less appropriate (Cohen et al., 2003). Childhood SES ratings were averaged and task conditions were assigned dummy codes (0 = inclusion, 1 = exclusion) prior to multiplication. Main effects were entered first (childhood SES, task condition). As in ANOVA, the contributions of main effects are assessed first to remove their contributions. Thereafter, the interaction term is assessed to check if any predictive power is added beyond that of the main effects themselves. If the interaction adds little predictive power, there is no reason to increase the complexity of the statistical model. The interaction between childhood SES and task condition was entered at the second step. When a significant interaction emerged at the second step, simple-effects analyses were conducted according to Aiken and West’s (1991) recommendations.

RESULTS

Preliminary analysis

Means and s.d.’s for all assessed variables and the zero-order correlations between variables are presented in Table 1. We initially examined the relationship between social distress and oxy-Hb changes in the rVLPFC (Δoxy-Hb) during each condition, to confirm that rVLPFC activity is associated with the regulation of social distress. A correlational analysis revealed that social distress was negatively correlated with Δoxy-Hb in the rVLPFC during the exclusion condition (r = −0.56, P < 0.001). No such correlation was found for the inclusion condition (r = −0.12, P = 0.56). As was found in a previous study (e.g. Eisenberger et al., 2003), these results suggest that rVLPFC activity is involved in the regulation of social distress during exclusion.

Predicting social distress and rVLPFC activity using subjective childhood SES

We used a hierarchical regression procedure to examine whether subjective childhood SES affected social distress and Δoxy-Hb levels in the rVLPFC during each condition (Table 2).

Regression analyses revealed that task condition significantly predicted social distress [β = 0.89, t(23) = 14.49, P < 0.001]. In addition, the interaction between subjective childhood SES and task condition was also a significant predictor [β = −0.17, t(23) = −2.78, P < 0.05]. This interaction is depicted in Figure 1. Subjective childhood SES was strongly associated with social distress during exclusion, but there was no such relationship for inclusion [exclusion, B = −0.18, t(23) = −2.48, P < 0.05; inclusion, B = 0.11, t(23) = 1.46, P = 0.16]. People with lower subjective childhood SES experienced higher levels of social distress during social exclusion, relative to people with higher childhood SES.

Finally, although we did not find a significant main effect of task condition [in analysis of raw score for Δoxy-Hb levels, β = −0.28, t(24) = −1.86, P = 0.08], regression analysis revealed that the

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<th>Table 1</th>
<th>Variables assessed in the present study: means, s.d.’s and zero-order correlations between variables</th>
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<tbody>
<tr>
<td></td>
<td>Mean (s.d.)</td>
</tr>
<tr>
<td>1. Subjective childhood SES</td>
<td>4.39 (1.14)</td>
</tr>
<tr>
<td>2. Social distress (Inclusion)</td>
<td>1.96 (0.36)</td>
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<tr>
<td>3. Social distress (Exclusion)</td>
<td>3.63 (0.52)</td>
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<td>4. rVLPFC activity (Inclusion)</td>
<td>0.33 (0.48)</td>
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<tr>
<td>5. rVLPFC activity (Exclusion)</td>
<td>0.11 (0.23)</td>
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*p < 0.05, **p < 0.01.

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<tr>
<th>Table 2</th>
<th>Predictors of social distress and rVLPFC activity</th>
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<tr>
<td></td>
<td>Social distress at Step 2*</td>
</tr>
<tr>
<td></td>
<td>β</td>
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<tr>
<td>Subjective childhood SES</td>
<td>−0.04</td>
</tr>
<tr>
<td>Condition (0 = inclusion, 1 = exclusion)</td>
<td>0.89**</td>
</tr>
<tr>
<td>Subjective childhood SES × Condition</td>
<td>−0.17*</td>
</tr>
</tbody>
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*R² = 0.81**, ΔR² = 0.03. **R² = 0.18*, ΔR² = 0.17**.
Inclusion

Subjective childhood SES was strongly and positively associated with social distress, significantly predicted \( \Delta O_{\text{Hb}} \) levels in the rVLPFC \( [\beta = 0.41, t(23) = 2.91, P < 0.01] \). This interaction is depicted in Figure 2. Subjective childhood SES was strongly and positively associated with \( \Delta O_{\text{Hb}} \) levels in the rVLPFC during exclusion, but not inclusion \( [\text{exclusion}, B = 0.47, t(23) = 2.68, P < 0.05; \text{inclusion}, B = -0.25, t(23) = -1.44, P = 0.16] \). Lower subjective childhood SES appears to be associated with reduced rVLPFC functioning during social exclusion.

**DISCUSSION**

The present study investigated whether lower subjective childhood SES would be associated with dampened rVLPFC activity, and therefore less regulation of distress, during social exclusion. This pattern was confirmed. The present findings suggest that lower subjective childhood SES could lead to dampened rVLPFC activity, which reflects the regulation of social distress under threatening circumstances.

This study provides the first evidence that subjective childhood SES moderates the neural responding that reflects the regulation of social distress. Although extensive research has implicated childhood SES as a moderator of successful coping across the lifespan, the exact nature of the neurocognitive mechanism that leads to such adaptive or maladaptive outcomes remains to be clarified. The present study provides some support for a subjective childhood SES mechanism, as well as the role of rVLPFC activation in the central processing of social distress. In particular, rVLPFC activity plays a key role in the exertion self-control via cortical-subcortical pathways (Wager et al., 2008; Cohen and Lieberman, 2010). Neuroimaging studies suggest that rVLPFC activation disrupts activity in the neural bases of negative affect, including the amygdala and dorsal anterior cingulate cortex (Lieberman et al., 2004). Similar results have been found in previous social exclusion studies (e.g. Eisenberger et al., 2003). The present study suggests that lower SES early family environments are associated with deficits in offspring coping-related neural functions (i.e. rVLPFC activity).

Considering alternative ways of interpreting the present data, rVLPFC activity reflects multiple functions across various domains. Notably, previous studies have confirmed that rVLPFC activity underlies working memory functioning (e.g. Kober et al., 2008) and attentional processing (e.g. Corbetta and Shulman, 2002). In this regard, it is necessary to consider whether rVLPFC activity in fact reflects the regulation of social distress per se. The present study seems to support this possibility, finding that self-reported social distress was negatively correlated with \( \Delta O_{\text{Hb}} \) in the rVLPFC during exclusion (but not inclusion).

There are some potential limitations of the present study. The use of NIRS to measure rVLPFC activity does pose some potential problems. We focused on rVLPFC activity, given that this brain region is involved in exerting self-control, and NIRS is also tolerant of participant’s body movements during a game. However, this approach did not allow us to investigate possible correlations between the rVLPFC and activation in other brain regions, or whether childhood SES moderates activity in other regions. Previous studies suggest that activity in other various brain regions is correlated with social distress (e.g. dorsal anterior cingulate cortex, insula, somatosensory cortex, thalamus and periaqueductal gray) (Lieberman and Eisenberger, 2009). Future studies should use fMRI to investigate whether subjective childhood SES may moderate activity in other brain regions under conditions of social threat.

Previous studies have confirmed that subjective perceptions of SES predict certain health outcomes, even better than do more objective indicators (Adler et al., 2000; Singh-Manoux et al., 2005), and childhood/adolescent SES appears to be a better predictor of health outcomes than adult SES (Kittleson et al., 2006). In addition, certain neural regions that underlie cognitive and emotional processing vary in size as a function of subjective perceptions of SES (Gianaros et al., 2007). This finding remains significant after controlling for conventional SES measures (e.g. income, education). We therefore focused on subjective childhood SES as measured by retrospective report, rather than more objective indicators. Based on previous studies (e.g. Taylor and Seeman, 1999; Adler et al., 2000; Repetti et al., 2002; Gianaros et al., 2007), we believe that various aspects of psychological functioning (e.g. self-esteem and optimism) are influenced by psychological perceptions of SES (i.e. subjective childhood SES) that could themselves be the product of the internalization of childhood economic adversity (i.e. objective childhood SES). Testing this possibility would require an investigation of the interrelationships between these variables using a longitudinal design.

Although the present study found a relationship between subjective childhood SES and rVLPFC activity during exclusion, potential causal mechanisms remain unclear. There are at least three possibilities. First, social distress appears to be moderated by psychosocial coping resources as well as social environmental factors (e.g. Gardner et al., 2005; Eisenberger et al., 2007; Kross et al., 2007; Yanagisawa et al., 2011). People with poor coping resources or adverse relationships appear to be particularly susceptible to social distress, and childhood SES seems to be implicated in such problematic scenarios (Taylor and Seeman, 1999; Repetti et al., 2002). A person who is brought up in an adverse socioeconomic environment has relatively fewer coping resources to invest in the management of threatening circumstances, and may therefore struggle to manage even temporary threats. In
this regard, and consistent with previous research (Hackman et al., 2010), the present findings suggest that childhood SES is associated with problems in neural development that have a clear impact on an individual’s ability to self-regulate. Second, a recent study suggests that people with lower subjective SES show higher neural activity in the mentalizing network (e.g. dorsomedial prefrontal cortex: Lieberman, 2010) while encoding social information (Muscattell et al., 2012). In addition, lower parental subjective social status is associated with an increased amygdala response to explicitly threatening faces (Gianaros et al., 2008). From these viewpoints, those with lower childhood SES are more likely to engage in mentalizing or thinking about others’ thoughts and feelings, resulting in greater appraisals of emotionality and sources of threat. Such appraisals may serve to obstruct rVLPFC activity under threatening circumstances. Thirdly, gene-related factors appear to influence brain activity under conditions of social threat. For example, a previous social exclusion study found that variation in the µ-opiopt receptor gene (OPRM1) is associated with dorsal anterior cingulate cortex functioning, which reflects appraisals of social distress during exclusion (Way et al., 2009). Given that such a trait is likely to be shared between parents and children, it is possible that regulatory brain activity associated with gene-related factors might itself be a causative factor in low SES. In examining these three possibilities, future studies should investigate the interrelationships between subjective (and objective) childhood SES, investment of coping resources, neural network development and gene-related factors, such that causal chain models that apply across the lifespan can be developed.

Conflict of Interest
None declared.

REFERENCES


