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Socioeconomic Disadvantage, Neural Responses to Infant Emotions, and Emotional Availability among First-time New Mothers

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Abstract

During the early postpartum period, mothers exhibit increased amygdala responses to positive infant expressions, which are important for positive mother-infant relationships. Socioeconomic disadvantage is associated with altered amygdala response to emotional stimuli as well as more negative mother-infant relationships. However, little is known about the role of socioeconomic disadvantage in neural responses specifically to infants. Thus, we examined whether socioeconomic disadvantage (indexed by lower income-to-needs ratio) is associated with neural responses to infant emotions and parenting behaviors among new mothers. Using fMRI, neural responses to infants' emotional expressions (positive, negative, and neutral faces) were assessed among 39 low- and middle-income first-time mothers during 0–6 postpartum months. Lower income-to-needs ratio was associated with dampened amygdala responses to positive infant faces, but increased amygdala responses to negative infant faces. An indirect effect of socioeconomic disadvantage on emotional availability via amygdala activation suggests that socioeconomic disadvantage is associated with heightened neural sensitivity to infants' negative emotions, which is further associated with mothers' intrusiveness observed during interactions with their own infant. The findings suggest that low-income mothers may be more vulnerable to altered neural processing of infants' emotional expressions which may further influence mothers' emotional availability during interactions with their own infants.

Keywords

Parenting; Amygdala; Infant Faces; Emotional Expressions; Maternal Behaviors; Neuroimaging

1. Introduction

During the early postpartum period, both structural and functional adaptation in the brain play an important role in parenting among new mothers (Kim, in press; Kim, Strathearn, &

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Swain, 2016b; Lonstein, Lévy, & Fleming, 2015). Among neural changes associated with parenting, researchers have identified that heightened amygdala sensitivity to infant emotional expressions, particularly positive expressions, play an important role in secure mother-infant attachment and sensitive parenting (Atzil, Hendler, & Feldman, 2011; Barrett & Fleming, 2011; Feldman, 2015; Swain et al., 2014). However, little is known about factors that may influence individual variations in neural responses to infant emotions among new mothers. Socioeconomic disadvantage increases exposure to unstable and stressful environments, which can hinder mothers' ability to provide optimal care for their own infants (Belsky & Jaffee, 2006; Coldwell, Pike, & Dunn, 2006; Conger & Donnellan, 2007; Whitesell, Teti, Crosby, & Kim, 2015). Thus, in the current study, we examined whether maternal socioeconomic disadvantage is associated with altered neural processing of infants' emotional expressions. We then examined whether the altered neural responses to infants' emotional expressions were associated with mothers' parenting behaviors during the early postpartum period.

The quality of maternal care during the early months of the first year has a significant long-term impact on infants' cognitive and emotional development (Bornstein, 2002). The concept of mothers' emotional availability has been used to describe and assess the quality of maternal care (Biringen & Easterbrooks, 2012; Bretherton, 1992; Emde, 1980). Emotional availability is based on Ainsworth's maternal sensitivity scale with a more explicit emphasis on the dyadic nature of emotions (both positive and negative) during mother-infant interactions. High emotional availability is characterized by mothers' own emotional expressions that are attuned to the child's emotional expressions. Among aspects of emotional availability to young children, maternal sensitivity (appropriate emotional expression and response to the child's expressions) and nonintrusiveness (emotional presence without overriding the child's needs) are highly relevant to mothers' appropriate understanding of emotional cues from their infants (Ainsworth, 1979). Difficulties in understanding infant emotions can be associated with low emotional availability behaviors such as intrusive or insensitive parenting, which can lead to negative mother-infant relationships and insecure infant-mother attachment (Belsky, 1993; Cicchetti & Toth, 2005; Killeen & Teti, 2012; Timmer, Thompson, Culver, Urquiza, & Altenhofen, 2012).

Given the importance of sensitive mothering during the first year, the neurobiological mechanisms of parenting have been studied using both animal and human models. Among the many neural regions involved in responding to infant emotional cues, the amygdala has been highlighted for its significant role in understanding emotional expressions of others (Adolphs, Tranel, & Damasio, 1998). The role of the amygdala in processing other's emotional cues is critically involved in parenting. In rodents, lesions in the amygdala impair maternal sensitivity (Numan et al., 2010), and mother-pup interactions increase *c-fos* changes in the amygdala (Fleming & Korsmit, 1996). In human mothers, the amygdala is activated by infant faces, indicating the role of the amygdala in detecting the salience of infant cues for parenting (Barrett & Fleming, 2011; Kim et al., 2016b; Seifritz et al., 2003).

However, postpartum factors that influence individual variations in amygdala responses to infant faces are still not well understood. A previous study suggests that lower levels of parental distress are associated with heightened amygdala responses to positive infant faces

among new mothers (Barrett et al., 2012). In the current study, we focused on the potential role of socioeconomic disadvantage in maternal neural responses to infants. Socioeconomic disadvantage has been linked to mothers' more limited emotional availability for their own infants (Little & Carter, 2005; Oyen, Landy, & Hilburn-Cobb, 2000). Socioeconomic disadvantage was also associated with increased maternal distress, which was then linked to reduced neural responses to infant cry in medial and middle prefrontal regions among first-time mothers (Kim, Capistrano, & Congleton, 2016a). However, this study did not examine the relations between neural activation and mothers' own parental behaviors nor include different types of infants' emotion cues. Therefore, the current study aims to examine whether neural processing of positive and negative infant cues, particularly in the amygdala, may be a pathway by which socioeconomic disadvantage influences observed parenting behaviors among new mothers.

Currently, there is converging evidence that socioeconomic disadvantage is associated with an individual's heightened amygdala reactivity to negative emotional cues such as negative adult faces (Gianaros et al., 2008; Javanbakht et al., 2015; Muscatell et al., 2012). Increased levels of stress have been suggested as one of the key pathways by which socioeconomic disadvantage is associated with elevated neural and behavioral reactivity to negative emotion (Hackman, Farah, & Meaney, 2010; Kim, Evans, Chen, Miller, & Seeman, in press; McEwen & Gianaros, 2010). Low-income mothers report higher levels of psychological distress during the postpartum period (Goyal, Gay, & Lee, 2010). Thus, socioeconomic disadvantage and associated emotional distress among new mothers may be associated with altered neural processing of infant emotional expressions, such as elevated neural responses to infants' negative expressions rather than positive expressions.

The current cross-sectional study examined whether socioeconomic disadvantage (assessed by lower income-to-needs ratio) was associated with neural responses to positive and negative infant faces, and further with parenting behaviors among low- and middle-income first-time new mothers. In the amygdala, we hypothesized that the interaction effects of income-to-needs ratio and infant emotion would be significant, and that lower income-to-needs ratio would be associated with altered amygdala activation, particularly reduced amygdala response to positive infant faces and increased amygdala response to negative infant faces. Increased levels of emotional distress among lower-income mothers may further be associated with variations in neural responses to infant faces. Moreover, we examined the indirect effect of socioeconomic disadvantage on parenting behaviors via the amygdala responses to infant emotions. We hypothesized that dampened amygdala response to positive infant faces and elevated amygdala response to negative infant faces would be associated with mothers' sub-optimal parenting behaviors, i.e. lower maternal sensitivity and higher maternal intrusiveness.

2. Materials and methods

2.1. Participants

First-time mothers with their biological infants at age 0–6 months were recruited through fliers and brochures in metro Denver areas, including midwifery clinics as well as the WIC (Women, Infant, and Children) and Colorado state Prenatal Plus programs to ensure

socioeconomic diversity in the sample. Eligible mothers were English-speaking and free from the following: pregnancy-related or infant medical illnesses involving more than a one-night stay in the neonatal intensive-care unit (NICU), current or historical psychiatric/neurological illness other than depression or anxiety diagnoses (to keep a controlled but ecologically valid community sampling approach), psychoactive drug use (except antidepressants), and magnetic metal in the body. Lower-income women were oversampled to be nearly half of the sample (see Family Income of the Measures section for more details). Of the 47 participants who were recruited, 8 mothers were excluded from analyses because they did not have complete fMRI data. Five mothers completed only home visits, two mothers were claustrophobic, and one mother had excessive motion above criteria (see fMRI data preprocessing for details). Thus, a total of 39 mothers were included in the analyses presented here. Among them, 27 participants were overlapping with the sample of a previously published paper using a different fMRI task (Kim et al., 2016a). Their demographic characteristics are described in Table 1.

Four participants reported a history of depression or anxiety disorder diagnosis. Participants were largely psychoactive drug free except one participant who reported using an antidepressant. Participants were relatively diverse in terms of their ethnicity/race with 43.6% reporting Caucasian and 41% reporting Hispanic background (Table 1). No demographic variable (i.e. maternal age, race/ethnicity, handedness, mood disorder status, breastfeeding status, postpartum month at the time of scan, mothers' time spent away from infants, infant's sex, or interval between home and fMRI visits) was associated with income-to-needs ratio, $rs(37) < 0.24$ or > -0.27 , $ps > 0.10$.

2.2. Procedures

Mothers were initially contacted by phone to assess their eligibility for the study. If eligible, a home visit was scheduled. During the home visit, mothers completed questionnaires and interviews on income and maternal mood. Mother-infant interactions were also video-recorded during the home visit. In a subsequent visit for the fMRI portion of the study, mothers visited the Intermountain Neuroimaging Center at the University of Colorado – Boulder. The average interval between home and fMRI visits was around 3 weeks (see Table 1). Participants received monetary compensation for their participation at the end of each visit, and child care and transportation support were provided to participants when needed.

2.3. Measures

2.3.1. Family income—Family income was assessed based on an income-to-needs ratio, calculated by dividing total family income by the poverty threshold specified by the U.S. Census Bureau. The range of the income-to-needs ratio was 0.44 to 6.34 (see Table 1), and 46% of the sample lived in poverty (income-to-needs ratio < 1) or near poverty (income-to-needs ratio > 1).

2.3.2. Maternal distress—Maternal distress was assessed by depressed mood and perceived stress. Maternal depressive mood was assessed by the Beck Depression Inventory (BDI) (Beck, Steer, & Garbin, 1988). The BDI includes 21 items which participants rated using a 4-point scale (from “absent” to “severe”). Perceived stress was measured using a

self-report measure of the Perceived Stress Scale (Cohen & Williamson, 1988). A total of 4 items (e.g. In the past month, how often have you felt it was difficult to control the important things in your life?) were rated using a 5-point scale (0=never, 4=very often).

2.3.3. Maternal behaviors—Maternal behaviors during interactions with own infant were coded using the Emotional Availability Scales 4th Edition (Biringen, 2008). At the home visit, mother-infant naturalistic interactions were video-recorded for 15 minutes. Mothers were instructed to interact with the infant as they typically do without using any toys to maximize direct interactions between mothers and infants. The unstructured and natural play setting is a common setting used to observe maternal behaviors during interactions with infants younger than 12 months, including studies using the Emotional Availability Scales (Biringen et al., 1999; Bornstein et al., 2006; Bornstein, Hahn, Suwalsky, & Haynes, 2011; Easterbrooks & Biringen, 2005; Wan et al., 2012)

The Emotional Availability Scales include scores on four maternal dimensions: sensitivity, structuring, non-intrusiveness, and non-hostility. In the current study, we focused on maternal sensitivity and non-intrusiveness, two dimensions that are key early elements of synchronous maternal behaviors during the first year of infancy that predict later secure infant-mother attachment (Feldman et al., 2009; Isabella, Belsky, & von Eye, 1989; Smith & Pederson, 1988). The sensitivity scale measures the ability of the mother to be appropriately emotionally connected to her infant and responsive to the infant's needs. A high score on the sensitivity scale reflects a mother who is affectively appropriate and responds to her infant's needs optimally. This mother would likely be positive and accepting while attending to the shifting demands of the infant as the dyadic relationship unfolds. The non-intrusiveness scale assesses the extent to which the mother follows her infant's lead in the interaction and interrupts the flow of play in a smooth manner. A high score on this scale would be seen in a mother who is available to the infant but does not overpower the infant's will or impose her own sense of how the interaction should go. Each scale ranged from 1 to 7, and the certified rater who coded the behaviors was blinded to the participants' socioeconomic background. To assess inter-rater reliability, two coders who were trained and certified by Dr. Biringen coded 25% of the sample, and intraclass correlations were performed, (ICC) = 0.713. The correlations between sensitivity and non-intrusiveness were moderate ($r = 0.38$, $p = 0.02$).

2.4. fMRI Paradigm

Participants viewed color images of positive, negative, and neutral expressions of two Caucasian infants. Each infant had 10 images of each expression. Many of the infants in the study were too young (< 3 months old) to provide positive expressions, so the paradigm utilized well-established positive, negative, and neutral infant stimuli instead of including images of each mother's own baby. The images have been included in several other published works (Strathearn, Fonagy, Amico, & Montague, 2009; Strathearn & Kim, 2015; Strathearn, Li, Fonagy, & Montague, 2008).

Faces were presented for 2000 ms followed by an average 1250-ms fixation cross (ranging from 500ms to 5350ms). A run included 90 face trials (30 trials of each expression). The trial order was randomized within a run. Total task duration was 310.10 seconds. Mothers

were asked to pay attention to each picture and experience their feelings and thoughts as they naturally occurred. Consistent with other studies using infant images (Strathearn & Kim, 2015; Strathearn et al., 2008), the passive viewing instruction was applied to avoid altering mothers' natural emotions and parenting-related thoughts in response to the images.

Upon completion of the scan, participants completed a computer task to rate each picture from the fMRI task (Strathearn et al., 2008). For each picture, participants were asked to respond to two questions, "How pleasant or unpleasant does each picture make you feel?" and "How do you think the baby in the picture was feeling?" on the scale of 1 = negative, 5 = neutral, and 9 = positive. The pictures participants saw were grouped into positive, negative, and neutral faces. The ratings of the two questions were positively correlated in each grouping of emotional pictures [$r(37) = 0.69$, $p < 0.001$].

2.5. fMRI data acquisition and processing

Scanning took place in a 3.0 Tesla Siemens magnet scanner using a standard 32-channel head coil. Functional data was acquired (540 T2*-weighted echo-planar-imaging (EPI) volumes; TR = 2,300 ms; TE = 27 ms; flip angle = 73; field of view = 192 mm; matrix size, 64×64 ; 36 axial slices; voxels = 3mm^3). High-resolution anatomical T1-weighted images using the 3D magnetisation-prepared rapid gradient-echo (MPRAGE) protocol were also acquired.

Analysis of Functional Neuroimages software (AFNI) (Cox, 1996) was used for preprocessing and statistical analysis. The first four pre-steady-state volumes in each run were discarded. Preprocessing included slice timing correction, motion correction, affine alignment, and normalization to the Talairach template. Spatial smoothing was applied using 4mm full width at half maximum blur estimates and intensity scaling.

2.6. Analysis

2.6.1. Behavioral ratings—We explored whether behavioral ratings of infant emotions are associated with income-to-needs ratio. Using SPSS (SPSS, Inc., Chicago, IL), an ANOVA analysis with (1) income-to-needs ratio as a between-subjects variable and (2) condition (positive, negative, neutral) as a within-subjects variable, was conducted for two behavioral rating outcomes: (1) emotional response to an infant's emotion and (2) perception of infant feelings. The interaction effects of income-to-needs ratio and infant emotion and the main effect of income-to-needs ratio were examined.

2.6.2. fMRI data—At the individual-subject level, regressors for each emotion were created by convolving stimulus trains with a gamma-variate hemodynamic-response function. Linear regression modeling was performed per voxel with the following regressors: three condition regressors, fourth degree polynomials modeling low-frequency drift, and six motion parameter regressors. Images with motion greater than 0.5 mm in any direction were censored. Data from a participant with excessive motion (above 20% of TRs removed) was excluded from analysis (see Participants section). In the data included in the analysis, the range of number of volumes censored was 0–21 ($M = 1.79 \pm 4.51$; median=0; below 16% of the total volumes). Thus, at least 101 volumes for each condition were included in the

analysis. Beta coefficients from the individual subject level were used in the group level analysis.

At the group level, a whole-brain linear mixed effects model with income-to-needs ratio (a continuous variable) as a between-subject factor, and condition (positive, negative, neutral) as a within-subject factor was conducted with 3dLME in AFNI (Chen, Saad, Britton, Pine, & Cox, 2013; Cox, 1996). To identify brain regions associated with income-to-needs ratio, we examined interaction effects and main effects with income-to-needs ratio. Based on previous studies and our *a priori* hypothesis, an ROI (region of interest) approach was used in the left and right amygdala. Small-volume correction for multiple comparisons was performed using an independently-defined mask of a 7-mm radius sphere [centered at x,y,z= -23,5, -15 for the right amygdala and x,y,z=23,5, -15 for the left amygdala (defined by AFNI)], and using the AFNI version 16.2.16 3dClustSim to establish a cluster-wise false positive probability of $P < 0.05$ (the cluster extent threshold of $k = 12$ at a height threshold of $p < 0.05$).

Other neural regions including the insula and orbitofrontal cortex have been shown to respond to infant faces (Lenzi et al., 2009; Nitschke et al., 2004; Strathearn et al., 2008). Thus, for completeness, we explored the interaction and main effect of income-to-needs ratio in the whole-brain analysis. Non-a-priori regions outside of the amygdala were corrected for multiple comparisons within the whole brain using the cluster extent threshold of $k = 45$ with a height threshold of $p < 0.005$, equivalent to a whole brain corrected false positive probability of $P < 0.05$, as calculated by 3dClustSim using the spatial autocorrelation function (acf) option within AFNI version 16.2.16. To characterize significant interactions, posthoc analyses were performed in SPSS using values extracted and averaged from the clusters.

The associations among income-to-needs ratio, emotional distress, neural activation in the suprathreshold clusters, and parenting behaviors were further examined using bivariate Pearson correlations in SPSS. Last, the indirect effect of income-to-needs ratio on mothers' emotional availability via amygdala response to infant emotion was examined using 95% bias-corrected Confidence Intervals with bootstrapping procedures (10,000 bootstrap resamples) of the PROCESS program (Preacher & Hayes, 2008).

3. Results

3.1. Behavioral rating analysis of infant faces

No interaction term or main effect of income-to-needs ratio was significant for either item. However, consistent with previous studies using similar stimuli (Strathearn et al., 2008), a main effect of condition was significant both in emotional response to an infant's emotion [$F(2,74)=86.01$, $p < 0.001$, $\eta^2_p = 0.70$] and perception of infant feelings [$F(2,74)=212.38$, $p < 0.001$, $\eta^2_p = 0.85$]. Mothers reported feeling more positive in response to positive infant faces ($M=7.51\pm1.06$) than neutral infant faces ($M=6.39\pm1.33$) and negative infant faces ($M=3.19\pm1.26$), $ps < 0.001$. Similarly, after viewing positive infant faces, mothers reported that infants were feeling more positive ($M=7.35\pm1.02$) compared with neutral infant faces ($M=5.94\pm1.15$) and negative infant faces ($M=2.67\pm0.83$), $ps < 0.001$. These behavioral

ratings were not associated with neural findings (described below) and maternal behavior data.

3.2.fMRI analysis of the associations between income and neural activation to infant faces

Consistent with the hypothesis that there would be significant interaction effects of income-to-needs ratio and infant emotion in the amygdala, using an ROI approach, a two-way interaction of income-to-needs ratio $\times$ condition (positive, negative, neutral) was identified in bilateral amygdala left parahippocampus/amygdala ($x, y, z = -25, -10, -13, k=55$) and right amygdala ($x, y, z = 26, -4, -19, k=42$) at $p < 0.05$, small volume corrected (Figure 1). Lower income-to-needs ratio was associated with dampened responses to positive infant faces in the left amygdala [$r(37)=0.36, p < 0.05$] while lower income-to-needs ratio was associated with enhanced neural responses to negative infant faces in the right amygdala [$r(37)= -0.37, p < 0.05$] (Figure 1).

The exploratory whole-brain analysis also revealed a significant two-way interaction of income-to-needs ratio $\times$ condition (positive, negative, neutral) in one cluster right insula (BA13; $x, y, z = 41, -13, 8, k=88$) at $p < 0.05$, whole-brain cluster-wise corrected (Figure 2). Post-hoc correlation analysis suggests that lower income-to-needs ratio was associated with enhanced neural response to positive infant faces [$r(37)= -0.45, p < 0.005$], and reduced neural response to negative infant faces [$r(37)=0.33, p < 0.05$] (Figure 2).

Income-to-needs ratio was negatively associated with perceived stress levels [$r(37) = -0.36, p < 0.05$] and, at a trend level, with depressive mood symptoms [$r(37) = -0.29, p < 0.10$]. However, mothers' emotional distress levels were not associated with amygdala activation in response to infant emotional faces.

3.3.Indirect effect of income-to-needs ratio on maternal emotional availability via amygdala response to infant emotions

Although no direct associations were found between income-to-needs ratio and emotional availability, the indirect effect of income-to-needs ratio on mothers' non-intrusiveness via the right amygdala response to negative infant faces was significant (Indirect effect=0.14, 95% CIs =0.01 0.35; Figure 3). Thus, lower income-to-needs ratio was associated with heightened amygdala responses to negative infant faces, which were further associated with lower scores of nonintrusiveness, suggesting high maternal intrusive behaviors. An analysis of maternal sensitivity did not reveal a significant indirect effect of income-to-needs ratio via amygdala responses to infant faces.

4. Discussion

The current study examined whether socioeconomic disadvantage is associated with neural responses to infant emotional expressions among first-time new mothers during the early postpartum period. As expected, socioeconomic disadvantage was associated with differential neural sensitivity to positive and negative infant emotions. In the amygdala, lower income-to-needs ratio was associated with reduced responses to positive infant faces, but elevated amygdala responses to negative infant faces. Furthermore, the current study examined whether differences in amygdala responses to infant emotions depending on

income-to-needs ratio may be associated with parenting behaviors. An indirect effect of income-to-needs ratio on mothers' emotional availability via amygdala responses suggested that the heightened responses to negative infant faces were associated with mothers' intrusiveness toward their own infant observed during interactions.

The amygdala plays a critical role in detecting and signaling salience of emotional cues (Adolphs, 2010; Anderson & Phelps, 2001). In past studies, socioeconomic disadvantage was associated with greater amygdalar reactivity to negative emotional stimuli of adult faces compared to positive emotional stimuli of adult faces (Javanbakht et al., 2015; Silverman, Muennig, Liu, Rosen, & Goldstein, 2009), suggesting increased salience and sensitivity to negative emotion among adults with socioeconomic disadvantage (Hackman et al., 2010; Kim et al., in press; Lupien, McEwen, Gunnar, & Heim, 2009; McEwen & Gianaros, 2010). The current study extended the literature by demonstrating the role of socioeconomic disadvantage in differential amygdala responses, specifically to infant emotional cues among new mothers. Lower-income mothers exhibited dampened amygdala response to positive infant faces, but elevated amygdala responses to negative infant faces. The findings suggest decreased salience of positive cues and increased salience of negative cues from infants among first-time new mothers. Such differences in the amygdala responses may further be associated with mothers' emotional responses to infant emotional cues. In a previous study, low-income mothers also exhibited reduced responses to infant cry sounds in the medial and middle prefrontal regions (Kim et al., 2016a). Together, this may point to altered neural regulation of infant distress cues among new mothers, as heightened amygdala and dampened prefrontal response to negative cues have been markers for altered affective processing and regulation (Etkin, Prater, Schatzberg, Menon, & Greicius, 2009; Ochsner, Silvers, & Buhle, 2012).

Furthermore, the elevated amygdala responses to negative infant faces were associated with mothers' parenting behaviors during interactions with their own infants. The indirect effect finding suggests that lower income-to-needs ratio was linked to the elevated amygdala response to negative infant faces, which was further associated with lower non-intrusiveness (or higher intrusiveness) expressed by the mothers during interactions with their own infants. There was no effect for maternal sensitivity. The finding is consistent with a previous study showing that elevated right amygdala responses to own infant cues was involved in high maternal intrusiveness, but not in maternal sensitivity (Atzil et al., 2011). The increased amygdala sensitivity to infants' distress cues and more intrusive maternal behaviors may be part of maternal expression of threat vigilance and protectiveness, and can be considered adaptive maternal responses to highly stressful and unpredictable environments such as living in poverty. Maternal intrusiveness, however, is a concern because it may be a risk factor for insecure attachment and suboptimal infant socioemotional development (Feldman, 2007; Feldman et al., 2009; Isabella et al., 1989; Smith & Pederson, 1988). Thus, follow-up work is needed to examine whether the neural responses to negative infant faces in new mothers prospectively predict infants' developmental outcomes as well as insecure infant-mother attachment at a later age.

In the exploratory whole-brain analysis, we found that the insula exhibited opposite associations between socioeconomic disadvantage and neural response to infant emotions

than observed in the amygdala. Lower income-to-needs ratio was associated with increased insular responses to positive infant faces, but reduced insular responses to negative infant faces. Together with the amygdala, the insula is involved in social and emotional information processing, but it is particularly important for considering the affectively charged states of others (Zaki, Davis, & Ochsner, 2012). Increased insula responses among new mothers are more often observed in response to infants' distress cues such as negative faces or crying sounds (Kim et al., 2011; Laurent, Stevens, & Ablow, 2011; Lenzi et al., 2009; Riem et al., 2011). Postpartum factors have been associated with altered insula response to infants. Postpartum depression is associated with reduced amygdala-insula connectivity in response to own infant images (Wonch et al., 2015). The current study expanded the literature by providing evidence that socioeconomic disadvantage is associated with altered insular responses reduced insular responses to negative infant faces in new mothers. Further research on the neural connectivity between the amygdala and insula and its relation to parenting behaviors is needed to better understand the role of the insula in processing infant emotions among low- and middle-income new mothers.

We tested a stress pathway of the associations between socioeconomic disadvantage and maternal amygdalar responses to infant emotions. As expected, low-income mothers reported higher levels of emotional distress, indicated by increased perceived levels of stress and depressed symptoms. However, maternal distress was not associated with amygdalar responses to infant emotions. This was a surprising finding. Low-income new mothers are vulnerable for a range of concurrent and/or chronic exposure to stressors including psychosocial stressors (e.g. violence, interpersonal conflict, discrimination, trauma), environmental stressors (e.g. substandard housing, crowding, noise), and childhood adversity (e.g. own parents' harsh parenting, emotional neglect) (Evans & Kim, 2010; Johnson, Riis, & Noble, 2016; Kim et al., in press; McEwen & Gianaros, 2010). These stressors influence amygdalar responses to emotional cues in adults (Dannlowski et al., 2013; Davidson & McEwen, 2012; Kim et al., 2013), thus, we speculate that emotional distress may fail to reflect the multiple stress pathways by which socioeconomic disadvantage influence amygdala responses to infant emotional cues. It should also be noted that our finding is inconsistent with previous studies showing that heightened levels of maternal distress were associated with new mothers' dampened amygdala responses to positive infant faces (Barrett et al., 2012) and reduced prefrontal responses to infant cry sounds (Kim et al., 2016a). The differences may be due to the fact that these two studies included own baby stimuli while the current study did not. Therefore, a future study including own and standard infant images is needed to examine the role of multiple domains of stressors in maternal amygdala activation.

The findings should be considered in light of limitations. First, the study paradigm did not include own infant images. Because many infants of the participants were too young to provide positive faces, we instead used standard infant images of positive, neutral, and negative expressions used in previous studies (Strathearn et al., 2009; Strathearn et al., 2008). However, the literature provides evidence of increased amygdala responses to own infant faces compared to other infant faces across different infant expressions (Leibenluft, Gobbini, Harrison, & Haxby, 2004; Ranote et al., 2004; Strathearn & Kim, 2015). Our findings suggest that the neural responses to these infant images may contribute to mothers' parenting behaviors for their own infants. However, as noted above, future studies should

examine specific links among socioeconomic disadvantage and maternal neural responses to own infants' emotional faces in later postpartum periods. Second, all images in the current study were Caucasian infants although participants had different racial and ethnic backgrounds. However, because income-to-needs ratio did not differ by race/ethnic backgrounds, there is not clear evidence that mothers' racial/ethnic background significantly influenced the findings related to income-to-needs ratio. It is important to note that individuals with racial and ethnic minority backgrounds are typically more likely to be low-income, thus it would be important for future work, using a larger sample, to match the participant's race/ethnicity with the race/ethnicity of the infants.

Third, the current study included a relatively small sample size ($N=39$), particularly compared to behavioral research examining the effects of family income on parenting. Lack of associations between income and demographic variables (e.g. race/ethnicity, a history of depression or anxiety disorder) in the current study is likely to be due to the small sample size. The small sample size also increases influences of each data point on statistical results. For instance, the associations between the income-to-needs ratio and the right amygdala responses to negative faces were no longer significant after removing the two highest values. While the two values were not detected as outliers by the Grubbs test (Grubbs, 1969), the result of the right amygdala require a caution until it is replicated in future studies with a larger sample size. Fourth, participants in the current study have a relatively wide range of infant age (0–6 months). This may have lowered the sensitivity of the data to detect specific associations among maternal variables included in the study, particularly the associations between income-to-needs ratio and mothers' emotional availability. However, it has been suggested that there can be a meaningful indirect effect via a mediator without a direct effect of the independent variable on the dependent variable (Hayes, 2009; MacKinnon, Fairchild, & Fritz, 2007). Nonetheless, future work with a larger sample and a targeted infant age would be needed to further confirm a mediating role of mothers' neural processes in the links between income and parenting. Fifth, in future studies, it will be important to examine other indicators of socioeconomic disadvantage and stress, including subjective social standing and maternal educational levels, as these have been associated with neural function in adulthood (Gianaros et al., 2007; Noble et al., 2012) and parenting (Brooks-Gunn & Markman, 2005). It will also be important to consider additional risk factors such as postpartum depression (Hipwell, Guo, Phillips, Swain, & Moses-Kolko, 2015), trauma (Kim, Fonagy, Allen, & Strathearn, 2014), substance use (Landi et al., 2011), and insecure attachment (Strathearn et al., 2009) for their interactions with socioeconomic disadvantage.

5. Conclusions

Although socioeconomic disadvantage has been associated with difficulties in adjustment to parenthood, little is known about maternal neural responses to infant emotions as a pathway by which socioeconomic disadvantage influences parenting behaviors among new mothers. The current study provides evidence for the role of socioeconomic disadvantage in differential sensitivity to infant emotional expressions among new mothers during the postpartum period. Socioeconomic disadvantage was associated with dampened amygdala responses to positive infant faces, but elevated amygdala responses to negative infant faces. The elevated amygdala responses to negative infant faces rather than positive infant faces

may reflect mothers' increased sensitivity to infants' distress cues. Elevated amygdala responses to negative infant faces were further associated with mothers' intrusiveness during interactions with their own infants. Intrusive parenting reflects mothers' heightened sense of vigilance, but can also present increased risk for negative parenting and insecure mother-infant attachment. This understanding of the associations among socioeconomic disadvantage, maternal neural function, and parenting behaviors may encourage consideration of the early postpartum period as a window when maternal brain sensitivity to infants may be vulnerable to socioeconomic disadvantage. Thus, the findings may support two-generation interventions that target both low-income mothers and their infants (Kim & Watamura, 2015; Shonkoff & Fisher, 2013; Smith, 1995) in order to provide more stable and safe environments and support positive mother-infant relationships.

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Highlights

- Low income was linked to neural processing of infants' emotions among mothers.
- Low income was associated with dampened amygdala response to positive infant faces.
- Low income was associated with elevated amygdala response to negative infant faces.
- The amygdala response was linked to more intrusive interactions with own infants.

Figure 1.

(a) Left parahippocampus/amygdala ($x, y, z = -25, -10, -13, k=55$) in a red circle showing income-to-needs ratio X condition interaction ($p < 0.05$, small volume corrected), and a scatterplot describing the positive associations between income-to-needs ratio and the neural responses to positive infant faces [$r(37)=0.36, p < 0.05$]; (b) Right amygdala ($x, y, z = 26, -4, -19, k=42$) in a red circle showing income-to-needs ratio X condition interaction ($p < 0.05$, small volume corrected) and a scatterplot describing the negative associations between income-to-needs ratio and the neural responses to negative infant faces [$r(37)=-0.37, p < 0.05$].

Figure 2.

(a) Right insula (BA13; $x, y, z = 41, -13, 8, k=88$) in a red circle showing income-to-needs ratio X condition interaction, $p < 0.05$, whole-brain cluster-wise corrected; (b) and (c) a scatterplot describing the negative associations between income-to-needs ratio and the neural responses to positive infant faces [$r(37) = -0.45, p < 0.005$] and negative infant faces [$r(37) = 0.33, p < 0.05$].

Figure 3.

A path diagram shows an indirect effect model with the unstandardized coefficients for each association. The indirect effect of income-to-needs ratio on non-intrusiveness via right amygdala responses to negative infant faces was significant (Indirect effect=0.14, 95% CIs =0.01 0.35), $*p < 0.05$.

Table 1

Characteristics of the participants and main variables

	N(%)	Mean $\pm$ SD	Range
Maternal age (years)	--	24.41 $\pm$ 5.22	18–36
Maternal Race/Ethnicity			
Caucasian	17 (43.6)	--	--
Hispanic	16 (41)	--	--
African-American	2 (5.1)	--	--
Others	4 (10.3)	--	--
Maternal education (years)	--	13.49 $\pm$ 2.38	7–18
Infant sex (female)	24 (61.5)	--	--
Postpartum month at the time of fMRI scans	--	3.97 $\pm$ 1.58	0.89–6.96
Income-to-needs ratio	--	2.47 $\pm$ 1.48	0.44–6.34
Maternal behaviors			
Sensitivity	--	5.24 $\pm$ 1.26	3–7
Nonintrusiveness	--	5.55 $\pm$ 1.26	3–7
Beck Depression Inventory (BDI)	--	6.97 $\pm$ 5.64	0–26
Perceived Stress Scale (PSS)	--	5.03 $\pm$ 2.89	0–11
History of depression or anxiety diagnosis (Yes)	4 (10.3)	--	--
Anxiety and depression medication use (Yes)	1 (2.6)	--	--
Interval between home and fMRI visits (months)	--	0.85 $\pm$ 0.69	0.07–3.42
Breastfeeding (and/or daily pump; but not exclusive formula-feeding)	38 (97.4)	--	--
Right handedness	33 (86.8)	--	--
Time away from own infant per week (hours)	--	11.92 $\pm$ 13.31	0–40